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ATLANTA ENGINEERING EXPERIMENT STATION J L SIMS OCT 85
AMSMI/RD-CR-85-10 DAAH01-83-D-A013

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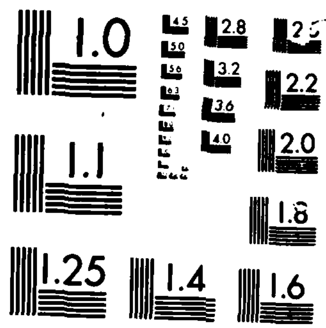

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TECHNICAL REPORT RD-CR-85-10

COMPONENT BASE FLOW ANALYSIS

Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30332

OCTOBER 1985

Prepared for:
Systems Simulations and Development Directorate
Research, Development, and Engineering Center

Contract No. DAAH01-83-D-A013

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898-5000

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER RD-CR-85-10	2. GOVT ACCESSION NO. AD-A166283	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) COMPONENT BASE FLOW ANALYSIS		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report April 19 thru Sept. 30, 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. L. Sims		8. CONTRACT OR GRANT NUMBER(s) DAAH01-83-D-A013 Delivery Order No. 0006 Project A-3522
9. PERFORMING ORGANIZATION NAME AND ADDRESS Georgia Institute of Technology Engineering Experiment Station Atlanta, Georgia 30332		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Missile Command ATTN: AMSMI-SS-AT Redstone Arsenal, Alabama 35898		12. REPORT DATE October 1985
		13. NUMBER OF PAGES 166
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Same as Item 11.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Supersonic Power-On Base Pressure
Component Model
Recompression Criterion

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A component model computer program for the solution of power-on base pressure at supersonic speeds has been modified to (1) include the effects of the upstream boundary layers upon the free shear layers and to (2) incorporate the angular recompression criterion developed by ONERA for the wake closure condition. After the program modifications were completed, an extensive set of calculations were made for comparison with experimental data. These

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20. Abstract (Continued)

comparisons showed that, in general, the calculated base pressures are greater than the experimental base pressures. This lack of agreement raises questions about the applicability of a single stream recompression criterion to the solution of the two stream problem.

SUMMARY

The base pressure computer program of Addy [4] has been modified to include the effects of the upstream boundary layers upon the free shear layers and to include the ONERA angular recompression criterion, as implemented by Wagner and White [12] for the wake closure condition. After the program modifications were completed, an extensive set of calculations were made to make comparisons with the calculations of Wagner and White and to make comparisons with a broad spectrum of experimental data. The comparisons with the calculations of Wagner and White showed very good agreement of the two calculations. Comparisons with the experimental data showed that, in general, the calculated base pressures are greater than experimental base pressures.

The Office National d'Etudes et de Recherches Aerospatiales (ONERA) angular criterion was originally developed for two-dimensional flow through a correlation of a comprehensive set of experimental data. Later, a factor to convert the two-dimensional criterion to an axisymmetric criterion was found through the correlation of a set of experimental data for axisymmetric flow. Both of these correlations were developed using data from a single-stream impinging upon a wall. The analysis of this data to define the critical angle is unique, and in turn, its application to a single-stream problem is unambiguous. However, when this criterion is applied to the solution of the two-stream problem, an ambiguity, either real or apparent, arises. In general, the criterion yields different reattachment pressures for the two streams. Since application of this criterion does not locate the reattachment points at different axial locations, different reattachment point pressures appear to be physically inconsistent. This raises a philosophical question as to whether or not any single-stream reattachment criterion can be rigorously applied to the two-stream reattachment problem.

Base pressures calculated for wide ranges of model parameters were compared to experimental data. These comparisons, in general, showed the calculated values to be greater than the experimental values. The size of this deviation does not vary greatly for the majority of the comparisons which were made. It seems that a relatively modest increase of the ONERA critical angle would bring the calculated data into good agreement with a majority of the experimental data which has been used. No such modification to the criterion has been attempted since it could only be done on an empirical, data fitting basis.

CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

1.0 INTRODUCTION

The concept and development of the so-called component model power-on base pressure analysis was pioneered by Dr. H. H. Korst and his coworkers at the University of Illinois. Their early work culminated in Reference 1, which documents the component analysis essentially as it is applied today. One of the attractive aspects of their method is that each component or element of the total number of components which comprise the solution may be of any selected degree of sophistication. Thus, any one of the components, may, in general, be improved or replaced by a more sophisticated component without revising or improving the entire program. In the formulations [1], Dr. Korst assumed that the free shear layers originated at the separation point on the body or nozzle and that a similar velocity profile existed at every point along the length of the shear layer, i.e., the upstream boundary layer thickness was neglected. He also assumed that the recompression process across the shocks at the wake closure was isentropic to the stagnation pressure of the dividing streamline.

Addy [2] developed a computer program to implement Korsts's analysis into a working engineering tool for the prediction of missile power-on base pressure at supersonic speeds. This program utilizes the method of characteristics to calculate the inviscid flow fields and the numerical solution techniques that are coded into the program are still state-of-the-art. However, the upstream boundary layers were not accounted for and the isentropic recompression criteria of Korst was used for the wake closure condition. A very limited comparison of calculated and experimental base pressures presented in Reference 2 showed reasonable agreement but the calculated base pressures were generally larger than the experimental data. In Reference 3, Addy developed an empirical modifying factor for the recompression pressure ratio which was a function of the nozzle radius to body radius ratio. The factor was developed by correlating calculated and experimental base pressure data with different values of this ratio. It was shown that this geometric parameter did a reasonable overall job of correlating the data. However, where a sufficiently large data base exists for a constant geometric ratio, significant factor variation was required to correlate all of the calculations. Addy further extended the utility of the computer program by modifying the external inviscid flow field calculation to account for boattailed and flared afterbodies. This work was published in Reference 4 and greatly increased the utility of the program from the standpoint of the number of configurations to which it could be applied. This final version of Addy's program still did not consider the upstream boundary layers, used the recompression factor [3] for cylindrical afterbodies, and used a recompression factor of one (original Korst criterion) for flared and boattailed afterbodies. An extremely limited comparison of calculated and experimental data for a boattailed afterbody showed the calculated data to be reasonable, but no general trend was established.

As discussed above, Addy's computational model was very good except that it neglected the upstream boundary layers and it needed a better recompression criterion. The computer program [4] was modified to include the effects of both the internal and external upstream boundary layers. This work, along with very limited calculations including the boundary layer effects, are reported in Reference 5. The boundary layer effects were included by modifying the shear layer mixing equations, by calculating an apparent origin shift

for the shear layer, and by retaining the assumption of a similar velocity profile. This modification prepared the program for an updated recompression criterion. Calculated results reported in this reference were for a wind tunnel test model with a nominal turbulent boundary layer thickness of the external stream. Calculations were made for this cylindrical afterbody configuration with and without the boundary layer terms using Addy's recompression factor and it was shown that including the boundary layer effect significantly increased the calculated base pressure. This is consistent with other results reported in the literature. It indicates that empirical correlation recompression factors derived without the boundary layer terms in the solution, have an inherent boundary layer effect included in the recompression factor. Thus, one should apply and evaluate recompression criteria with computational models which contain the boundary layer terms and are as complete as possible in other respect. The modified Addy computer program meets these criteria.

The goals of the present work are: (1) to include one of the currently available recompression models in the computer program, and (2) to assess the adequacy of the model by comparing calculated and experimental base pressures for a large data base. Since Korst's original development, a number of recompression criteria have been proposed by different authors. Several of these will be briefly discussed as a short survey of the overall activities in this area.

One of the earliest proposals for a recompression criterion was made by Nash [6], who simply proposed that the Korst isentropic pressure rise be multiplied by a constant to obtain the recompression pressure rise. On the basis of a very limited amount of experimental data, Nash established a value of 0.35 for this factor in the supersonic flow case. Another approach to the recompression criterion is the Page criterion which is presented in Reference 7, with References 8 and 9 discussing application techniques. The Page criterion is based on a correlation of experimental data which model the ratio of the flow turning angle at the reattachment point to the total turning angle as a function of the discriminating streamline velocity ratio. Carriere and Sirieix [10, 11] developed an angular reattachment criterion which correlated the effective turning angle of the reattaching streamline as a function of the inviscid flow Mach number. In Reference 12, Wagner and White studied the effects of the initial boundary layers and some of the recompression models. They found that over a considerable range of free streamline Mach numbers, the Page criterion and the Office National d'Etudes et de Recherches Aerospatiales (ONERA) angular criterion gave very similar reattaching streamline turning angles.

The Page model and the ONERA angular criterion are of special interest because both are presented in the form of simple correlations which are based upon comprehensive sets of experimental data. Both techniques relate the recompression process to the angular deflection at the reattachment point. Each also assumes that the stagnation pressure of the discriminating streamline is equal to the reattachment static pressure. However, in the application of the Page model, an iterative procedure is necessary to calculate the length of the constant pressure mixing region [8] even for the single stream problem. Wagner and White [12] reported serious convergence problems when trying to implement the Page model for the two-stream base pressure problem. Therefore, it was decided to restrict the present investigation to consideration of the ONERA angular criterion for the recompression calculation.

2.0 ONERA RECOMPRESSION CRITERION

2.1 General Discussion

The ONERA angular criterion is based upon the correlation of a body of data from a set of systematic experiments [11]. These experiments were arranged so that they corresponded essentially to a vanishing upstream boundary layer. In addition, the change in reattachment angle caused by blowing into the base is correlated with Korst's basic theory. Thus, the recompression turning angle for the no-bleed, no-initial boundary layer is to be taken from an experimental data correlation; however, the effect of bleed or boundary layer influence may be predicted analytically. With these empirically established facts at hand, it was postulated that the basic angular criterion could be formulated as

$$\Psi = \Psi(M_a, C_q) \tag{1}$$

For the usual application of the criterion, it is assumed that the boundary layers are thin with only a small bleed. In this case, it is permissible to linearize Equation (1) so that

$$\Psi = \overline{\Psi}(M_a) + C_q \left.\frac{\partial\Psi}{\partial C_q}\right|_{\eta=\eta_j} \tag{2}$$

where C_q is a general bleed coefficient defined by

$$C_q = -\sigma\left(\frac{m_b}{\rho_a U_a L} + \frac{\theta}{L}\right) \tag{3}$$

where σ is included in the definition of C_q to make it compatible with the upstream boundary layer effects on the mixing layer equations (see Equation 33 of Reference 5). The critical angle $\overline{\Psi}(M_a)$ for vanishing C_q is obtained from the ONERA data. This data was obtained for an isoenergetic, two-dimensional flow with the ratio of specific heats, γ, = 1.4. Thus, rigorously, the application of this criterion should be restricted to these flows; however, equations for the non-isoenergetic case will be derived. For application of Equation (2) to the practical calculation of base pressure, the function $\overline{\Psi}(M_a)$ needs to be given in analytical form. An empirical curve fit for $\overline{\Psi}(M_a)$ was first given by Solignac and Delery in Reference 13 as:

$$\overline{\Psi}(M_a) = 57.3\,(0.569 - 0.5096/M_a) \tag{4}$$

where $\overline{\Psi}$ is in degrees. Later, Wagner, in Reference 14, developed a polynomial curve fit of the data of the form

$$\overline{\Psi}(M_a) = 57.3\,(0.044 + 0.172\,M_a - 0.018\,M_a^2) \tag{5}$$

This equation also yields $\overline{\Psi}$ in degrees. The free streamline Mach number for the ONERA data varies from approximately 2.0 to 4.0 and both of the empirical equations fit the data very well in this Mach range. However, when the equations are used to extrapolate $\overline{\Psi}$ beyond the data range, sizable differences occur, and there is no substantial evidence to suggest that either is superior to the other. Therefore, solutions for base pressure which utilize free streamline Mach numbers outside of the data range should be treated with some caution. A comparison of the critical angle $\overline{\Psi}$ deduced from the above equations and other sources is presented in Figure 1 which is taken from Figure 6 of Reference 14. It is seen that not only do the equations agree well with the ONERA data, but that the Page model also yields critical angles which agree well with the ONERA data.

2.2 Isoenergetic Equations

With the relationship for the critical angle $\overline{\Psi}$ established in a usable format, we turn to the task of evaluating the partial derivative in Equation (2). As discussed above, Korst's basic theory accurately predicts the change in the turning angle. Since the ONERA investigations do not alter the concept of isentropic recompression up to the reattachment point, the angular change of the dividing streamline, $\Delta\Psi$, up to the reattachment point, must be equal to the reattachment angle calculated with the basic Korst theory. So, we have

$$\Delta\Psi = \omega(M_a) - \omega(M_R) = \Psi_{Korst} \qquad (6)$$

where, ω is the Prandtl-Meyer function and M_R is the Mach number of the adjacent inviscid streamline at the reattachment point. Since the C_q effect changes only the streamline angle up to the point of reattachment and the angle change from downstream of the reattachment points is independent of C_q, then there results:

$$\frac{\partial\Psi}{\partial C_q} = \frac{\partial(\Delta\Psi)}{\partial C_q} = - \frac{\partial\omega(M_R)}{\partial C_q} = - \frac{d\omega}{dM_R} \times \frac{\partial M_R}{\partial C_q} \qquad (7)$$

where $\frac{\partial M_R}{\partial C_q}$ will be defined later. Now, the gradient of the Prandtl-Meyer function is given by Reference 15, pg 466, Equation (15-3).

$$d\omega = \frac{\sqrt{M^2-1} \quad dM^2}{2M^2 \quad 1+\frac{\gamma-1}{2}M^2} \qquad (8)$$

Then,

$$\frac{d\omega}{dM} = \frac{\sqrt{M^2-1}}{M \quad 1+\frac{\gamma-1}{2}M^2} \qquad (9)$$

Now the recompression on the reattaching streamline is still assumed to be isentropic and the total pressure on the discriminating streamline is equal to the static pressure at reattachment. Then, using the usual isentropic relations, there results

$$\frac{P_R}{P_B} = \frac{P_R/P_{oa}}{P_B/P_{oa}} = \left[\frac{1 + \frac{\gamma-1}{2} M_a^2}{1 + \frac{\gamma-1}{2} M_R^2}\right]^{\frac{\gamma}{\gamma-1}}$$

$$= \frac{P_{od}}{P_B} = \left(1 + \frac{\gamma-1}{2} M_d^2\right)^{\frac{\gamma}{\gamma-1}} \tag{10}$$

where M_d is the Mach number on the discriminating streamline. This Mach number can now be expressed as

$$M_d^2 = \frac{U_d^2}{a_d^2} = \frac{U_d^2}{U_a^2} \times \frac{U_a^2}{a_a^2} \times \frac{a_a^2}{a_d^2} = \phi_d^2 M_a^2 \frac{T_a}{T_d} \tag{11}$$

and for the present assumption of isoenergetic flow, the relationship between the temperature ratio and the Crocco number is given by

$$\frac{T}{T_a} = \frac{1 - \phi^2 C_a^2}{1 - C_a^2} \tag{12}$$

which yields

$$M_d^2 = \phi_d^2 M_a^2 \left[\frac{1 - C_a^2}{1 - \phi_d^2 C_a^2}\right] \tag{13}$$

The relationship between the Crocco number and the Mach number is given by Equation (51) of Reference 16

$$C_a^2 = \frac{\frac{\gamma-1}{2} M_a^2}{1 + \frac{\gamma-1}{2} M_a^2} \tag{14}$$

and when this result is substituted into Equation 13, there results

$$M_d^2 = \frac{\phi_d^2 M_a^2}{1 + \frac{\gamma-1}{2} M_a^2 (1-\phi_d^2)} \tag{15}$$

After substituting Equation (15) into the right-hand side of Equation 10 and simplifying

$$\frac{P_{od}}{P_B} = \left[\frac{1 + \frac{\gamma-1}{2} M_a^2}{1 + \frac{\gamma-1}{2} M_a^2(1-\phi_d^2)}\right]^{\frac{\gamma}{\gamma-1}} \tag{16}$$

The left-hand side of Equation 10 is now combined with Equation 16 to give

$$\left[\frac{1 + \frac{\gamma-1}{2} M_a^2}{1 + \frac{\gamma-1}{2} M_R^2}\right]^{\frac{\gamma}{\gamma-1}} = \left[\frac{1 + \frac{\gamma-1}{2} M_a^2}{1 + \frac{\gamma-1}{2} M_a^2 \ (1-\phi_d^2)}\right]^{\frac{\gamma}{\gamma-1}} \tag{17}$$

Equation 17 can be solved for M_R to obtain

$$M_R^2 = (1 - \phi d^2)M_a^2 \tag{18}$$

To continue toward the evaluation of the derivative in Equation (2), Equation (7) must be further expanded by the chain rule to obtain

$$\frac{\partial \Psi}{\partial C_q} = - \frac{d\omega}{dM_R} \times \frac{\partial M_R}{\partial \phi_d} \times \frac{\partial \phi_d}{\partial C_q} \tag{19}$$

Differentiating Equation (18) results in

$$\frac{\partial M_R}{\partial \phi_d} = - \frac{\phi_d \ M_a}{\sqrt{1-\phi_d^2}} \tag{20}$$

Combining Equations (18), (19), and (20) with Equation (9) evaluated at the reattachment point gives

$$\frac{\partial \Psi}{\partial C_q} = \frac{\phi_d \sqrt{M_R^2-1}}{(1-\phi_d^2)\left(1+ \frac{\gamma-1}{2} M_R^2\right)} \quad \frac{\partial \phi_d}{\partial C_q} \tag{21}$$

where we still have the requirement to evaluate $\frac{\partial \phi_d}{\partial C_q}$. This can be done by writing the integral equation for the mass flow in the shear layer up to the discriminating streamline in the form (Equation C-41 of Reference 17)

$$I_1(\eta_d) = \int_{\eta \, Rb}^{\eta \, d} \frac{\rho}{\rho_a} \phi d\eta = I_1(\eta \, Ra) - I_2(\eta \, Ra) + C_q \tag{22}$$

Now $I_1(\eta_{Ra})$ and $I_2(\eta_{Ra})$ are constants, and therefore independent of C_q, so when Equation (22) is differentiated with respect to C_q, there is obtained

$$\frac{\partial \eta_d}{\partial C_q} \quad \frac{\rho(\eta_d)}{\rho_a} \quad \phi_d = 1 \tag{23}$$

Expanding Equation (23) by the chain rule and solving the resultant equation for $\frac{\partial \phi_d}{\partial C_q}$ yields

$$\frac{\partial \phi_d}{\partial C_q} = \frac{\rho_a}{\rho(\eta_d)} \frac{1}{\phi_d} \frac{\partial \phi_d}{\partial \eta_d} \tag{24}$$

The velocity profile in the shear layer is defined by the error function, so

$$\phi = \frac{1}{2}\left[1 + \operatorname{erf}(\eta)\right] = \frac{1}{2}\left[1 + \frac{2}{\pi} \int_0^{\eta} e^{-\eta^2}\, d\eta\right] \tag{25}$$

which yields upon differentiation

$$\frac{\partial \phi}{\partial \eta} = \frac{1}{\sqrt{\pi}} e^{-\eta^2} \tag{26}$$

and using isentropic relations

$$\frac{\rho_a}{\rho(\eta_d)} = \frac{1 - \phi_d^2 C_a^2}{1 - C_a^2} \tag{27}$$

Now, when Equations (26) and (27) are combined with Equation 24

$$\frac{\partial \phi_d}{\partial C_q} = \frac{1 - \phi_d^2 C_a^2}{1 - C_a^2} \frac{1}{\phi_d} \frac{1}{\sqrt{\pi}} e^{-\eta_d^2} \tag{28}$$

The final step is to substitute Equation (28) into Equation (21) use Equation (18) for the definition of the M_R, and make the approximation $\eta_j = \eta_d$, the result is

$$\frac{\partial \Psi}{\partial C_q} = \frac{\sqrt{M_a^2 (1-\phi_j^2) - 1}}{(1-\phi_j^2)\left[1 + \frac{\gamma-1}{2} M_a^2 (1-\phi_j^2)\right]} \frac{1 - \phi_j^2 C_a^2}{1 - C_a^2} \frac{1}{\sqrt{\pi}} e^{-\eta_j^2} \tag{29}$$

This completes the derivation of the equations required for the application of the ONERA recompression criterion to the restricted case for isoenergetic flow. Values of η_j and ϕ_j are determined by Korst's theory in the course of each base pressure iteration as a function of C_a, and therefore, can be assumed to be known for application to the solution of the recompression criterion.

2.3 Non-Isoenergetic Equations

The extension of the application of the ONERA recompression criterion to non-isoenergetic flows is discussed by Delery and Sirieix [18] and also by Wagner [14]. Since missile design cases are non-isoenergetic flow cases, the equations for this situation are given herein. Delery and Wagner use somewhat different approaches for determining the critical angle, $\bar{\Psi}$, for this case, but they use approximately the same approach for determining the derivative term. Using the same approach as Delery, it is assumed that

$$\Psi = \Psi(M_a, \Lambda_d, C_q) \tag{30}$$

and when C_q is small

$$\Psi = \bar{\Psi}(M_a, \Lambda_d) + C_q \frac{\partial \Psi}{\partial C_q}(M_a, \Lambda_d) \tag{31}$$

where

$$\Lambda_d = \frac{T_{od}}{T_{oa}} = \frac{T_{ob}}{T_{oa}} + \phi_d \left(1 - \frac{T_{ob}}{T_{oa}} \right) = \Lambda_b + \phi_d (1 - \Lambda_b) \tag{32}$$

The analysis to determine the derivative, $\frac{\partial \Psi}{\partial_q}$ proceeds as in the isoenergetic case, but with greater complication due to the temperature effect. Since the process is identical, this development will be presented in a summary manner with critical steps related to the equations in Section 2.1. The first significant non-isoenergetic effect occurs in the temperature equation for the discriminating streamline Equation (12) which is

$$\frac{T_d}{T_a} = \frac{\Lambda_d - \phi_d^2 C_a^2}{1 - C_a^2} \tag{33}$$

And when this relation is inserted into Equation (11), the following definition for the discriminating streamline Mach number

$$M_d^2 = \frac{\phi_d^2 M_a^2}{\Lambda_d \left(1 + \frac{\gamma - 1}{2} M_a^2\right) - \frac{\gamma - 1}{2} \phi_d^2 M_a^2} \tag{34}$$

When Equation (34) for M_d^2 is substituted into the right-hand side of Equation (10) and the resultant is simplified and solved for M_R,

$$M_R^2 = M_a^2 \left(1 - \frac{\phi_d^2}{\Lambda_d} \right) \tag{35}$$

Now Equation (32) is substituted into Equation (35) and the resultant equation is differentiated to obtain

$$\frac{\partial M_R}{\partial \phi_d} = - \frac{M_a \phi_d}{\sqrt{1 - \phi_d} \times \sqrt{\Lambda_b + \phi_d}} \times \frac{\Lambda_b + \Lambda_d}{2 \Lambda_d^{3/2}} \tag{36}$$

As in the isoenergetic case,

$$\frac{\partial \Psi}{\partial C_q} = \frac{\partial \Psi}{\partial M_R} \times \frac{\partial M_R}{\partial \phi_d} \times \frac{\partial \phi_d}{\partial C_q} \tag{37}$$

and when all the derivatives along with Equation 35 are substituted into Equation 37,

$$\frac{\partial \Psi}{\partial C_q} = \frac{\sqrt{M_a^2 \left(1 - \frac{\phi_j^2}{\Lambda_j}\right) - 1}}{\left[1 + \frac{\gamma - 1}{2} M_a^2 \left(1 - \frac{\phi_j^2}{\Lambda_j}\right)\right]} \times \frac{\phi_j}{\sqrt{(1 - \phi_j)(\Lambda_b + \phi_j)\left(1 - \frac{\phi_j^2}{\Lambda_b}\right)}} \times \frac{\Lambda_b + \frac{1}{2}(1 - \Lambda_b)}{\Lambda_j^{3/2}} \times \frac{\Lambda_b + \phi_j(1 - \Lambda_b) - \phi_j^2 C_a^2}{\sqrt{\pi}\, \phi_j\, (1 - C_a^2)} e^{-\eta_j^2} \tag{38}$$

Thus, it is seen that the effect of non-isoenergetic flow on the angular gradient can be correctly calculated by the above analysis. However, this effect upon the critical angle, in the absence of experimental data, is subject to some conjecture. Delery [18] proposed a modification of $\overline{\Psi}$ for gases with a ratio of specific heats, γ, different from 1.4. However, he did not propose a temperature ratio modification. Wagner [14] following the proposal of Sirieix, et al [11], used a blowing correction to a modified version of Equation (31). This modified equation is

$$\Psi = \overline{\Psi}_{Korst}\,(C_a, T_{od}/T_{oa}) + (\varepsilon + C_q) \frac{\partial \Psi}{\partial C_q} (C_a, T_{od}/T_{oa}) \tag{39}$$

where the blowing correction, ε, proposed by Wagner is defined by

$$\varepsilon = 0.2934 - 0.1773\, M_a + 0.04132\, M_a^2 - 0.00311\, M_a^3 \tag{40}$$

in order for Ψ to be approximately equal to the ONERA $\overline{\Psi}$ when $C_q = 0$. Wagner suggests that these results are applicable to the non-isoenergetic case and for values of γ that are different from 1.4. These modifications to the basic criteria are easily implemented within the basic MICOM Base Pressure program and therefore, were selected to be used in the program modification and subsequent calculations.

2.4 Modified ONERA Criterion

Wagner and White [12] and Wagner [14] developed a modified ONERA criterion to account for interference effects in the two stream base pressure problems which are not present in the single stream problem. From a physical point of view, it appears that the pressures in both recompression zones should become equal at the point of reattachment. The ONERA criterion uses the slip streamline angle to establish the turning angle, Ψ; whereas the modified criterion uses this direction only as a first approximation and then varies the direction until the pressure ratio becomes equal in the two shear layers. This technique uses an iteration procedure which varies the reattachment angle, Ψ, that produces a change in the mass flow coefficient when Equation (2) is solved for C_q. This leads to a change in ϕ_d, and thus, produces a corresponding change in the pressure ratio from Equation (16).

For the application of this modified criterion, it is necessary to compute the pressure ratio at each step. Therefore, the velocity ratio ϕ_d is required and is computed from a relationship involving ϕ_j and C_q. Wagner [14], showed that while a linear relationship is satisfactory for Equation (2), it would be necessary to use a second order Taylor series expansion to achieve comparable accuracy in the calculation of ϕ_d. Therefore,

$$\phi_d = \phi_j + C_q \left.\frac{\partial^2\phi}{\partial C_q{}^2}\right|_j + \frac{C_q{}^2}{2} \left.\frac{\partial^2}{\partial C_q{}^2}\right|_j \tag{41}$$

where, for the non-isoenergetic case

$$\frac{\partial\phi}{\partial C_q} = \frac{\Lambda - \phi^2 C_a{}^2}{1-C_a{}^2} \; \frac{1}{\phi} \frac{1}{\sqrt{\pi}} \, e^{-\eta^2} \quad . \tag{42}$$

and, the second derivative can be expressed as,

$$\frac{\partial^2\phi}{\partial C_q{}^2} = \frac{\partial\phi}{\partial C_q} \left\{ - \frac{\frac{T_{ob}}{T_{oa}} + \phi^2 C_a{}^2}{1-C_a{}^2} \; \frac{1}{\phi^2}\frac{1}{\sqrt{\pi}} \; e^{-\eta^2} - 2\,\frac{\Lambda - \phi^2 C_a{}^2}{1 - C_a{}^2} \; \frac{\eta}{\phi} \right\} \tag{43}$$

Utilizing Equations (42) and (43) with Equation (41), there results

$$\phi_d = \phi_j + C_q \left.\frac{\partial\phi}{\partial C_q}\right|_j \left\{ 1 - \frac{C_q}{\phi_j{}^2(1-C_a{}^2)} \left[\left(\frac{T_{ob}}{T_{oa}} + \phi_j{}^2 C_a{}^2 \right) \frac{e^{-\eta_j{}^2}}{2\sqrt{\pi}} + \left(\Lambda_j - \phi_j{}^2 C_a{}^2\right) \eta_j \phi_j \right] \right\} \tag{44}$$

and

$$\left.\frac{\partial\phi}{\partial C_q}\right|_j = \frac{\Lambda_j - \phi_j{}^2 C_a{}^2}{1 - C_a{}^2} \; \frac{1}{\phi_j} \; \frac{e^{-\eta_j{}^2}}{\sqrt{\pi}} \tag{45}$$

which completes the equations necessary to implement Wagner's modified ONERA criterion.

2.5 Axisymmetric Reattachment

The original development of the ONERA angular criterion was based upon data taken for two-dimensional flow and the critical reattachment angle presented in Figure 1 is restricted to the two-dimensional case. Solignac and Delery [13] conducted a series of systematic tests to establish a set of reattachment data for axisymmetric flow. Using similarity considerations and this data base, they were able to establish a correlation parameter relating the axisymmetric reattachment data to the two-dimensional critical angle. Therefore, in order to apply the ONERA criterion to the solution of the axisymmetric base pressure problem, this correction must be applied to the two-dimensional critical angle. This correlation is

$$\Delta\bar{\Psi} = \bar{\Psi}_{AX} - \bar{\Psi}_{2-D} = f(F) \qquad (46)$$

and ONERA found that

$$f(F) = 2.7 - 3.5 \tan (5.4F - 4.4) \qquad (47)$$

did an excellent job of correlating the differences between the two-dimensional and axisymmetric experimental data. In Equation 47, F is the ratio of the two-dimensional to axisymmetric spread rate parameters and is given by

$$F = \frac{\phi_{2-D}}{\phi_{AX}} = \frac{1}{Lr_R} \int_o^L rds \qquad (48)$$

where L is the length of the shear layer and r_R is the radius at the reattachment point. Correlation of the two sets of data by this function is presented in Figure 2 which has been taken from References 14 and 18. The axisymmetric data was obtained from three experiments as illustrated by the insets on the figure. In the first case, there was a large angle cone with slender forward cylinder and a small angle cone ahead of the cylinder. The forward cone was larger in diameter than the cylinder so the surface streamlines separated from the model at the base of the forward cone. Reattachment occurred on the surface of the large angle cone. A second series of experiments was performed with an under expanded supersonic nozzle which was surrounded by an external shroud. In this case, the plume boundary expanded out of the nozzle and the reattachment was on the external shroud. The third test to obtain data used an axisymmetric body with a rearward facing step followed by a cylindrical afterbody. Streamlines separated from the forward surface at the step and reattachment was on the downstream cylinder. The function F must be calculated for both flow boundaries in the axisymmetric base pressure problem and then the critical angles are obtained by applying the correction. All of these calculations are easily performed within the framework of the basic MICOM Base Pressure program.

3.0 COMPUTER PROGRAM MODIFICATIONS

With the completion of the present work, there have been two stages of modifications on the Addy base pressure program which are documented in Reference 4. First, the effects of the upstream boundary layer and the effective shear layer origin shift were included in the program and were documented in Reference 5. In the present work, the ONERA recompression criterion and a

modified ONERA criterion have been included to replace the empirical recompression coefficient derived by Addy[3]. Most of the calculations for the new recompression criterion have been included in the subroutine TJMIX of the original program. The solutions for these criteria implemented in this subroutine have been adapted from the Wagner and White program which was also based upon the MICOM Base Pressure program.

The program has been run for a large number of isoenergetic cases and has proven to be very reliable when operating in this mode for either the standard or modified ONERA criterion. Results from these calculations will be discussed and compared with some available experimental data in Section 4.0 of this report. A limited number of non-isoenergetic cases were successfully run with both internal and external gases having a ratio of specific heats equal to 1.4. However, when the ratio of the inner to outer stream temperatures became large, the program would fail. The program would not operate for the non-isoenergetic case when the internal gas ratio of specific heats was not equal to 1.4. Therefore, it is apparent that irrespective of the performance of the angular criterion in the basic isoenergetic case for which it was developed, additional development will be required before it can be used for the general non-isoenergetic missile design case.

This program is available as a private user (P) file in the Perkin-Elmer account which was assigned to the delivery order under which this study was performed. It is also available on a backup tape for safekeeping. The file name for this problem is 'BPRESOC' which stands for Base Pressure-ONERA Criterion. Even though the program is named ONERA criterion, it will also calculate with the modified criterion by selecting the appropriate value of a logical variable. The progrm is set up to run in an interactive mode on the Perkin-Elmer 3230 with the option to either use a data file for most of the data or to input all of the data interactively. A definition of the Perkin-Elmer interactive screen cues and input data is presented in Appendix A. The complete FORTRAN listing of the program is printed in Appendix B to provide a permanent record of the current state of the program.

4.0 PRESENTATION OF RESULTS

Calculations have been performed for a large number of isoenergetic cases for comparison with experimental data and with Wagner and White's calculations which are presented in Reference 12. Some reasonably recent data such as that presented in Reference 19 were found and most of the data sources that Addy used for his empirical correlation [3] will be presented. The various comparisons which are given represent a rather wide cross section of geometric configurations, nozzle configurations, and free stream Mach numbers. Generally, the data sample seems sufficiently large to support any general conclusions that might be reached.

4.1 Comparison with Wagner and White's Results

Wagner and White [12] compared results from their calculations with experimental data for several cases. Calculations were performed with the present progrm to compare with the Wagner and White calculations and the appropriate experimental data is included to complete the theory to data comparison. Figure 3 presents the comparison of the two sets of calculations and experimental data for a cylindrical afterbody configuration of Agrell and

White [19]. The Wagner and White calculations were extracted from Figure 5 of that paper. Wagner and White investigated the effects of origin shift, spread rate parameter, and recompression criterion. From these and various other results, it was concluded that the ONERA origin shift [11], and the Korst and Tripp [20] spread rate parameter definition would be used exclusively in the current investigation. The two sets of calculations for the standard and modified ONERA criteria agree extremely well, as indeed they should. The difference between the modified and standard criteria is small at low pressure ratios and it steadily increases as the pressure ratio increases. Agreement between the modified criterion calculations and the experimental data is very good at the higher pressure ratios and not quite so good at the lower pressure ratios. Also included in this figure as a reference for the recompression criterion effect, are calculations using the original Korst isentropic recompression with the boundary layer terms and origin shift included. Figure 4 presents the mathematical variation of the base pressure as a function of the upstream boundary layer momentum thickness for the cylindrical afterbody configuration of Figure 3 for a pressure ratio equal to 3.0. Current calculations for both the standard and modified criteria are compared to the same types of calculations by Wagner and White. Again, there is excellent agreement between the two sets of calculations while both types of calculations somewhat overpredict the experimental data point extracted from Figure 3. One important observation from this figure is the relatively small gradient of the base pressure with increasing momentum thickness beyond a nominal thickness value. Therefore, for experimental reports which do not include boundary layer data, it appears to be reasonable to estimate the momentum thickness using engineering methods.

A comparison of the same types of calculations for this same configuration as shown in Figure 3 is shown in Figure 5, but the free stream Mach number has been increased to 3.27. There is, again, excellent agreement of the results from the two programs for both the standard and modified ONERA criteria and also for calculations using the Addy recompression coefficient. Calculated results using the two ONERA criteria agree well with the experimental data at low pressure ratios but a• ~ery much greater at the higher pressure ratios. This is inverse to the trend of Figure 3. Figure 6 continues this series of comparisons of calculations and experimental data. For the first time, there are differences between the current calculations and those of Wagner and White. The configuration for the data of Figure 6 is a six-degree conical boattail afterbody. The other analytical comparison in the figure utilizes an empirical recompression coefficient for boattailed bodies which was developed by Dr. White through a correlation of the experimental data [19]. Since there is extremely good agreement between these two solutions, a strong indication that both programs are performing the boattail flow field solution correctly, the difference between the solutions utilizing the two ONERA criteria is puzzling. A final comparison of current calculations between the Wagner and White calculations and the experimental data [21] is presented in Figures 7 through 10. Figure 7 presents the base drag coefficients for all three configurations for which data is presented in Reference 21. Since the base drag coefficient is somewhat insensitive to the base pressure ratio, it was decided to recast the data of Figure 7 into the base pressure ratio and this is presented in Figures 8 through 10 for the three different nozzles. There are small differences between the current calculations and the Wagner and White calculations. However, the differences between the calculations are greater for the largest nozzle. Two comparisons with calculations published by

Dr. Wagner [14] are presented in Figures 11 and 12. Figure 11 compares calculated results from the two programs with additional data from Reference 21. The model configurations for the data presented in this figure are a cylindrical afterbody with a sonic nozzle and a Mach 2.0 nozzle with uniform parallel flow in the exit plane. Current calculations agree well with Wagner's calculations and both sets predict base pressures somewhat higher than the experimental data. Figure 12 presents a comparison of results from the two programs for two configurations for which test data is available in Reference 22. The current calculations yield greater values of base pressure than do Wagner's calculations for both the ONERA criterion and the modified criterion. This disparity is disturbing because it seriously affects the difference between the calculations and the experimental data. However, a concerted analysis of the current calculations failed to disclose any reason for the differences between the two sets of calculations.

Overall, the comparisons of the current calculations with those of Wagner and White show good to excellent agreement. This instills confidence that the analyses and program modifications have been executed correctly. On the other hand, comparisons of calculated and experimental results show some cases of good agreement and some of poor agreement. However, more comparisons of calculated and experimental data need to be made before drawing any conclusions concerning the overall prediction capability of the computer program.

4.2 Comparisons with Experimental Data

The overall effectiveness of the base pressure computer program in predicting base pressure will be judged by a broad based comparison of calculated and experimental data. Addy [3] collected a wide ranging data base to develop the correlation for his recompression coefficient. Since Addy's report was published, Agrell and White published Reference 19 which contains considerable additional data. Experimental data for the comparisons to be discussed in this section will be obtained from these sources. Figure 13 completes the comparison of the current calculations with the data of Reid and Hastings (see Reference 21). Figures 7 through 11 for the other comparisons. Agrell and White [19] published a rather comprehensive set of data for cylindrical and boattailed models at two free stream Mach numbers and two different nozzles. Some of the data indicates that flow separation occurs forward of the base for the larger boattail angles and pressure ratios. This data was not used for comparison with calculations since the current program does not have flow separation prediction capability. Some of the Agrell and White data is presented in Figures 3, 5, and 6. The rest of the Agrell and White data for attached flow on the afterbody are compared with current calculations for both the standard and modified ONERA criteria in Figures 14 through 20. In general, the calculated base pressures are larger than the experimental values. The amount of the overprediction depends on the nozzle characteristics, boattail angle, and free stream Mach number. At $M_\infty = 2.01$, the basic trends of both calculated and experimental data are quite similar over the pressure ratio range. However, at $M_\infty = 3.27$, the variation of the experimental data over the pressure ratio range is much smaller than the variation of the calculations.

Experimental data of Bromm and O'Donnel [22] are compared with calculated values of base pressure and presented in Figure 13 and in Figures 21 through 25. Bromm and O'Donnell obtained data at three free stream Mach numbers, two nozzle sizes and three nozzle wall angles. Once again, the calculated data are, in general, greater than the experimental data; however, the amount of the overprediction varies significantly from case to case. It is suspected that some of this variation is due to experimental uncertainties, especially for the ten degree nozzle exit angle. Qualitative trends are well predicted by the calculated results and the experimental trends remain similar for all three free stream Mach numbers. Baughman and Kochendorfer [23] published data for bodies with five different boattail angles with the base to nozzle radius ratio determined by the boattail length. The models were each tested with constant size nozzles that produced different exit plane Mach numbers. These nodel and nozzle combinations were tested at free stream Mach numbers of 1.91 and 3.12. Comparisons of calculated and experimental base pressures for these conditions are presented in Figures 26 through 38. Again, the calculated data, in general, is greater than the experimental data. Qualitative trends are well predicted for the Mach 1.91 data. However, the trend of the variation with pressure ratio was not well predicted for the Mach 3.12 data and this same result was observed in the comparisons with the Agrell and White data.

The next set of comparisons presented is with the data of Henderson [24]. These comparisons are limited to Henderson's cylindrical afterbody configuration and they are presented in Figures 39 through 44. All of the calculated base pressures are greater than the corresponding experimental data. Thus, the trend that has been established through all the previous comparisons continues without exception. Comparisons of calculated base pressures with the experimental data of Reference 25 are presented in Figures 45 through 53. The configuration for the data and calculations of Figures 45 to 47 is a cylindrical afterbody with a small nozzle and the mismatch of data with calculations is probably the largest yet observed. However, this follows the trend of the Reid and Hastings data presented earlier. The remainder of the data is for nine-degree boattail models and significant mismatches have been observed for similar configurations in earlier comparisons. Figures 54 and 55 present comparisons of calculated base pressures with experimental data of Cortright and Schroeder [26]. As in all previous comparisons, the calculated values are greater than the experimental values. Data from Harries [27] are compared to the calculated base pressures in Figures 56 through 60. The isoenergetic data of Reid [28] is compared to the equivalent calculated values in Figures 61 and 62. Comparisons of calculated base drag coefficients with experimental data [29] is presented in Figures 63 through 65. The data presented is for the no-bleed test cases. Since the predicted base drag coefficient is lower than the test data, the predicted base pressure continues to be greater than experimental values. Also, at a Mach number of 3.5, the trend over the pressure ratio range is not well predicted. This continues the pattern noted in comparisons which were previously discussed. Figures 66 through 69 present comparisons of calculated base pressures with single jet experimental data from Reference 30. This is the only set of data which generally agrees with the calculations. The geometric configuration is quite similar to configurations for which comparisons have been discussed previously where calculations and data did not agree. Therefore, it is felt that this set of data is not consistent with the rest of the data base. The final comparisons to be presented are shown in Figures 70 through 73 where the data is taken from Reference 31. These figures show the usual trend of the calculated values being greater than the experimental data.

COMPUTER PLOT LABEL DEFINITIONS

Ordinates

PB/PE	Ratio of base pressure to free stream static pressure
CD-B	Base drag coefficient
CP-B	Base pressure coefficient

Abscissae

PI/PE	Ratio of nozzle exit plane static pressure to free stream static pressure
THETA/R	Ratio of external boundary layer momentum thickness to maximum body radius
POI/PE	Ratio of nozzle stagnation pressure to free stream static pressure

Parameters

BETAe	Body (external flow) angle at base
BETAi	Nozzle wall angle at exit plane
Me	Free stream Mach number
Mi	Nozzle exit plane Mach number
Ri/R	Ratio of nozzle exit radius to maximum body radius
THETA/R	Ratio of external boundary layer momentum thickness to maximum body radius

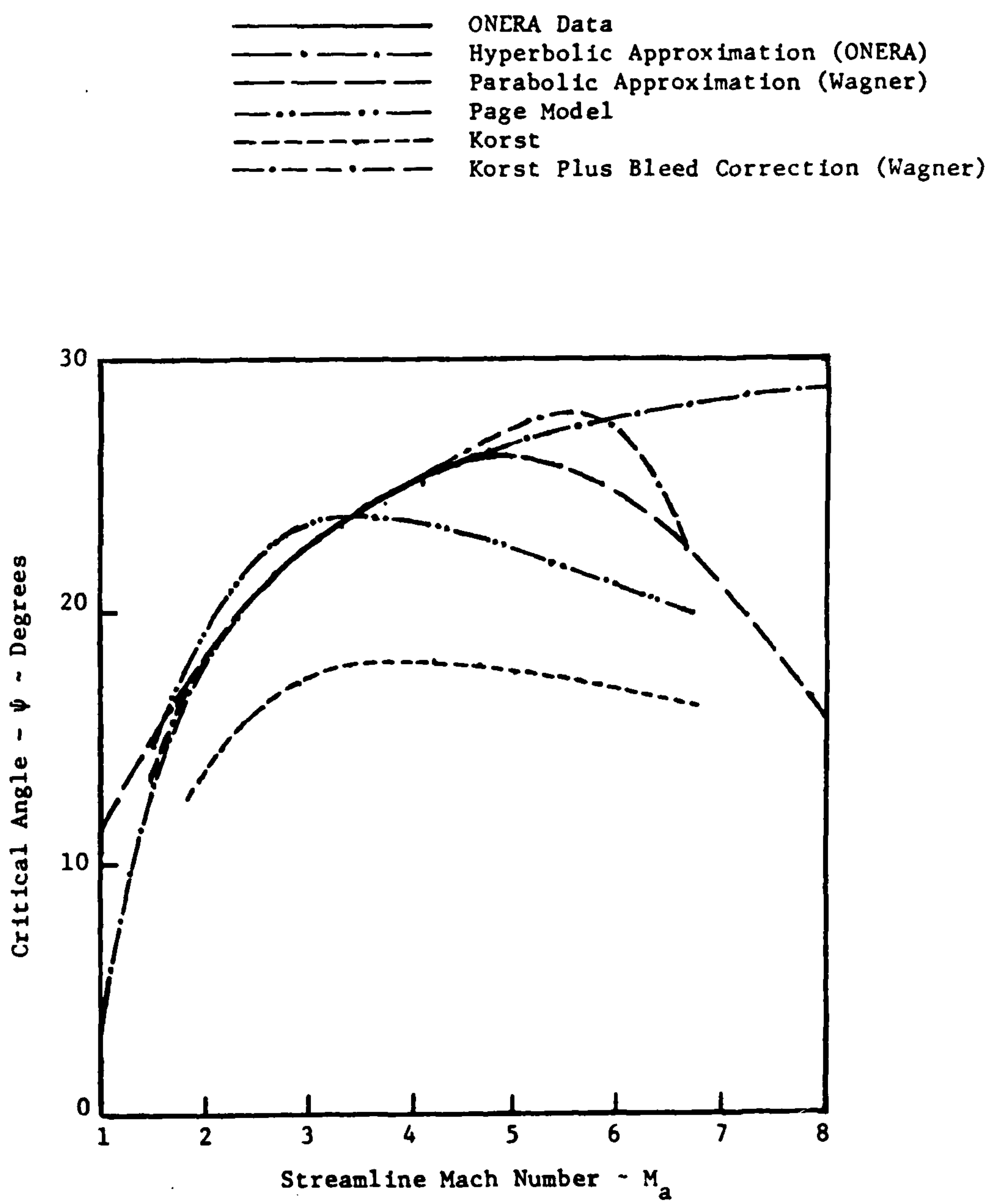

Figure 1. Critical recompression angle.

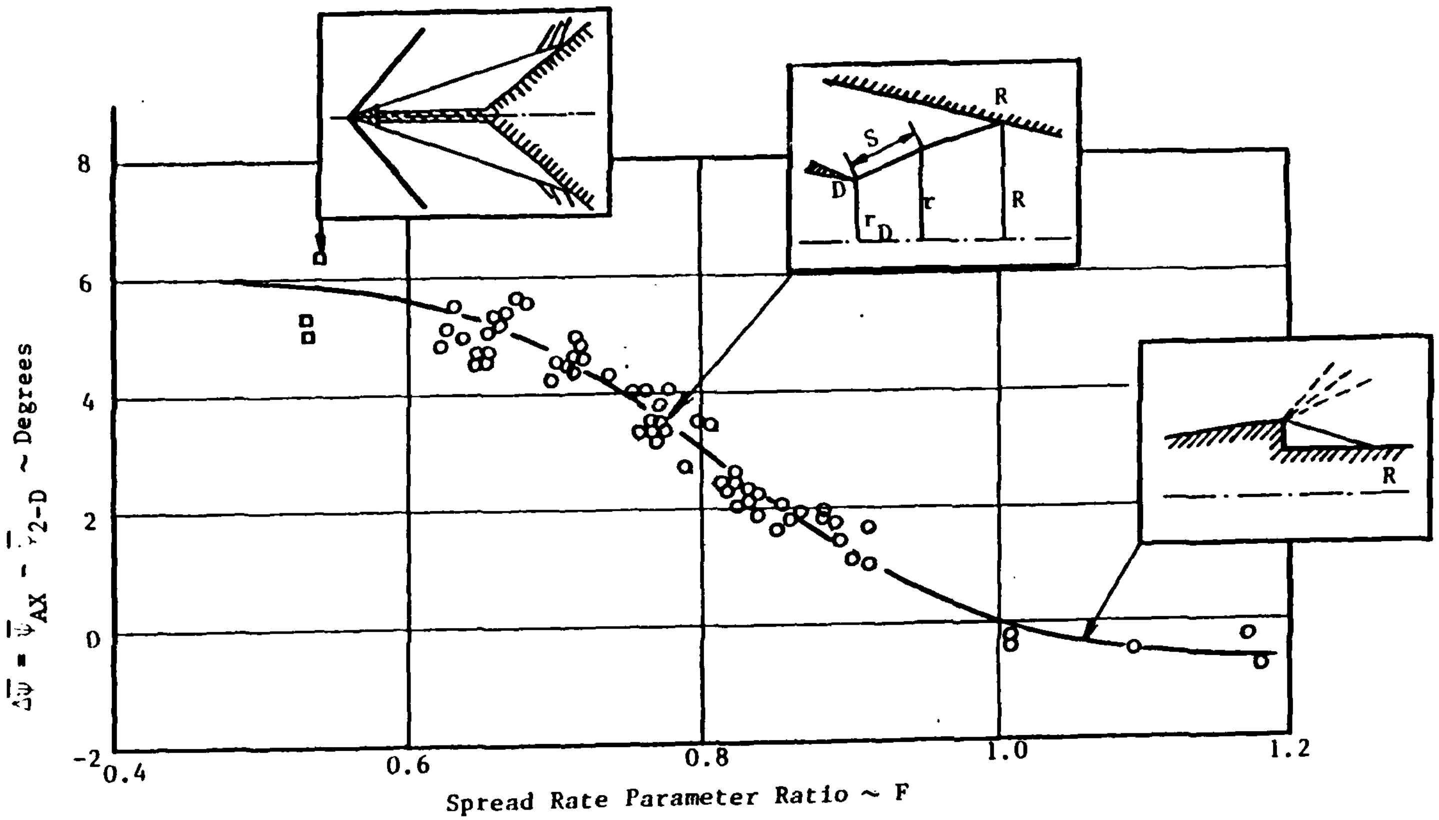

Figure 2. Axisymmetric correction to the critical recompression angle.

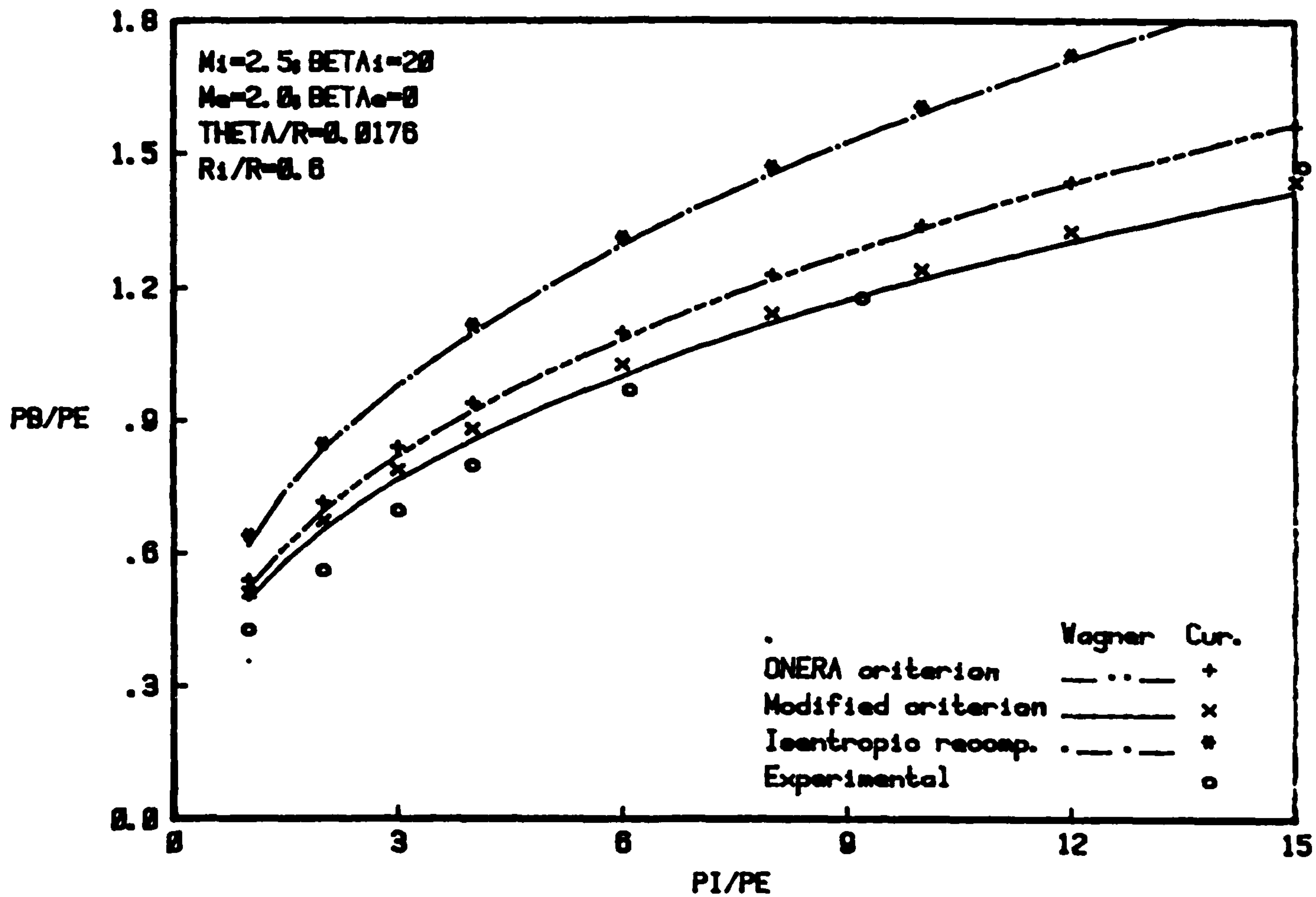

Figure 3. Comparison of current base pressure calculations with Wagner and White's calculations and experimental data from Reference 19 for a cylindrical afterbody configuration at $M_\infty = 2.0$.

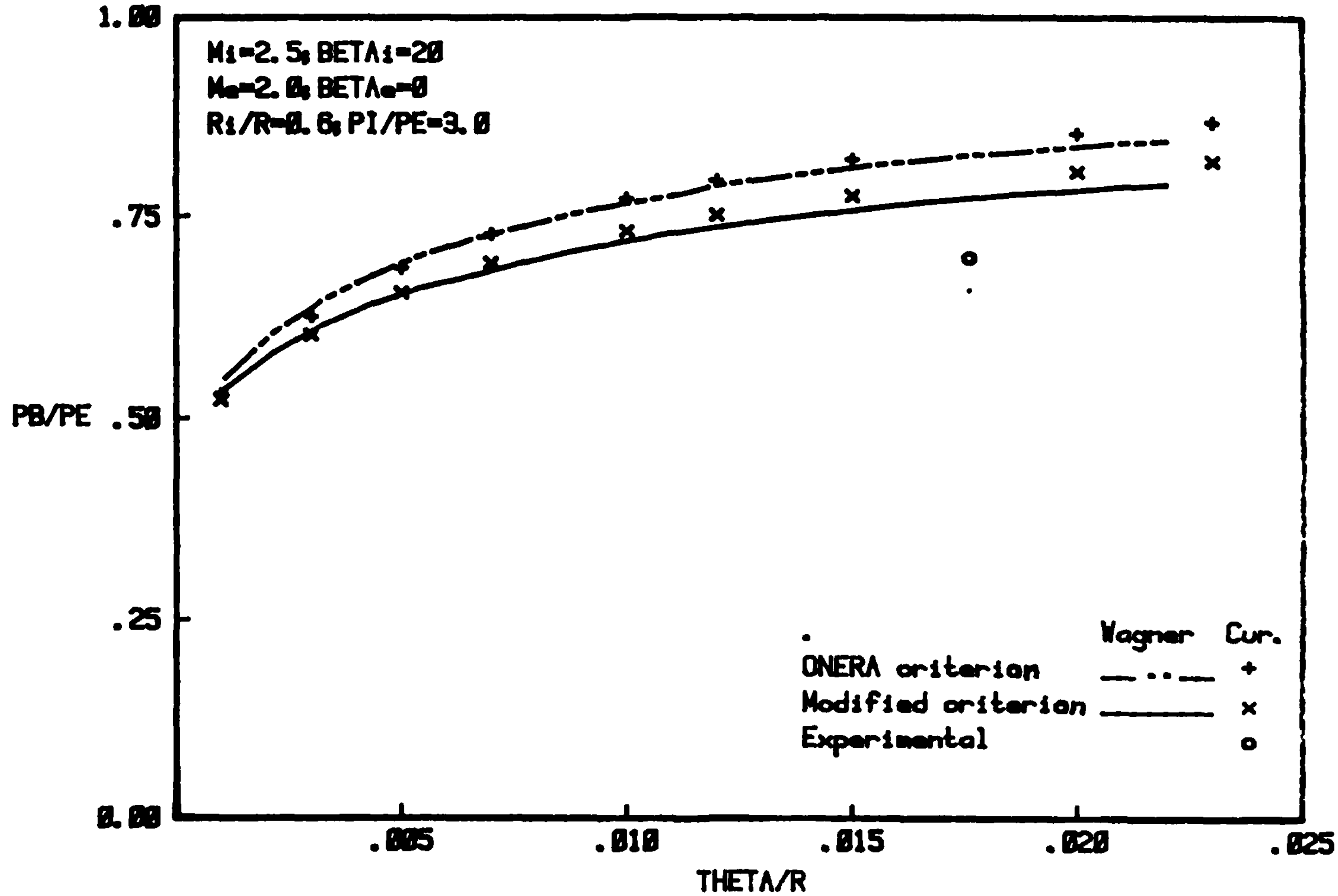

Figure 4. Comparison of current base pressure calculations with Wagner and White's calculations for variable boundary layer momentum thickness.

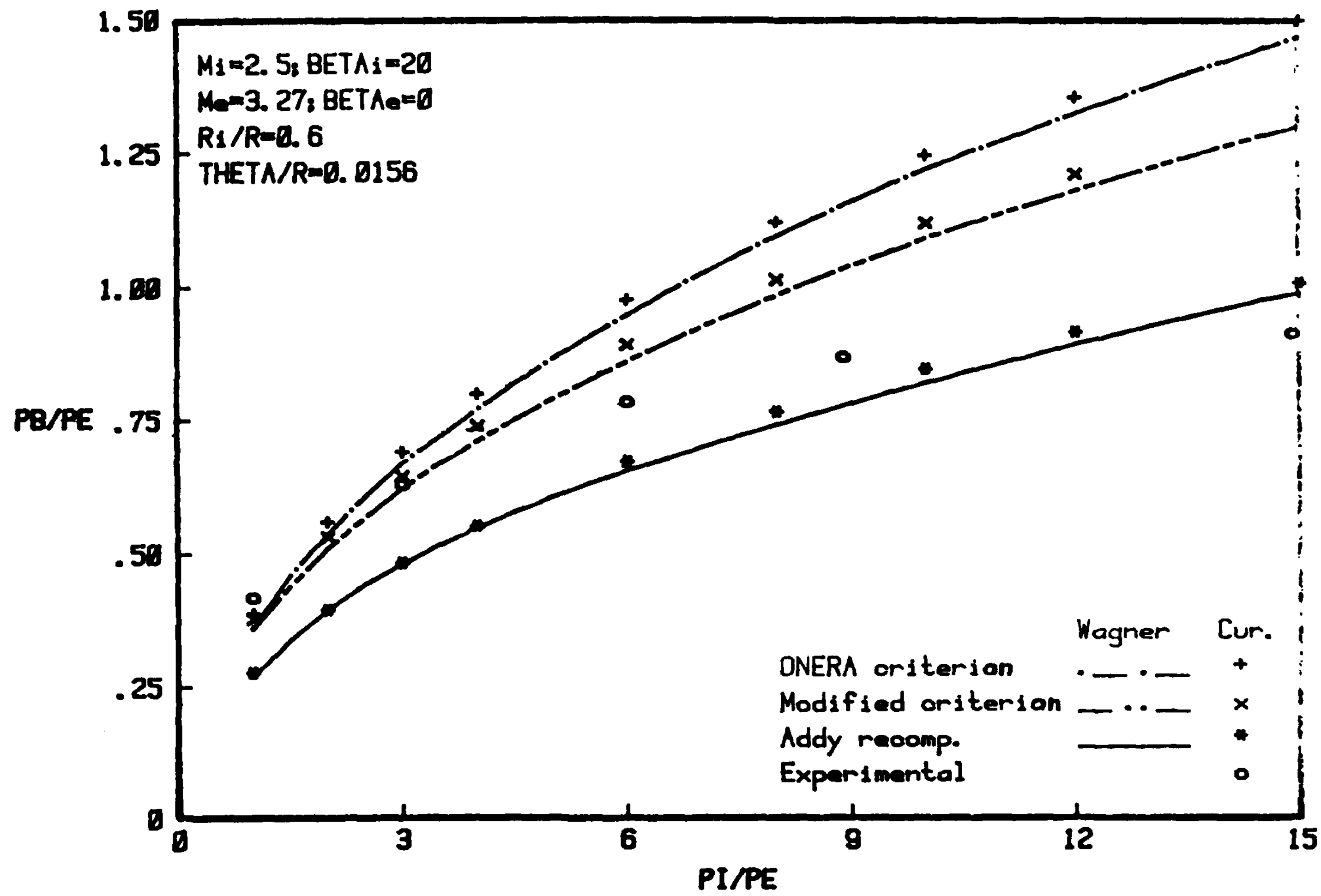

Figure 5. Comparison of current base pressure calculations with Wagner and White's calculations and experimental data from reference 19 for a cylindrical afterbody configuration at $M_\infty = 3.27$.

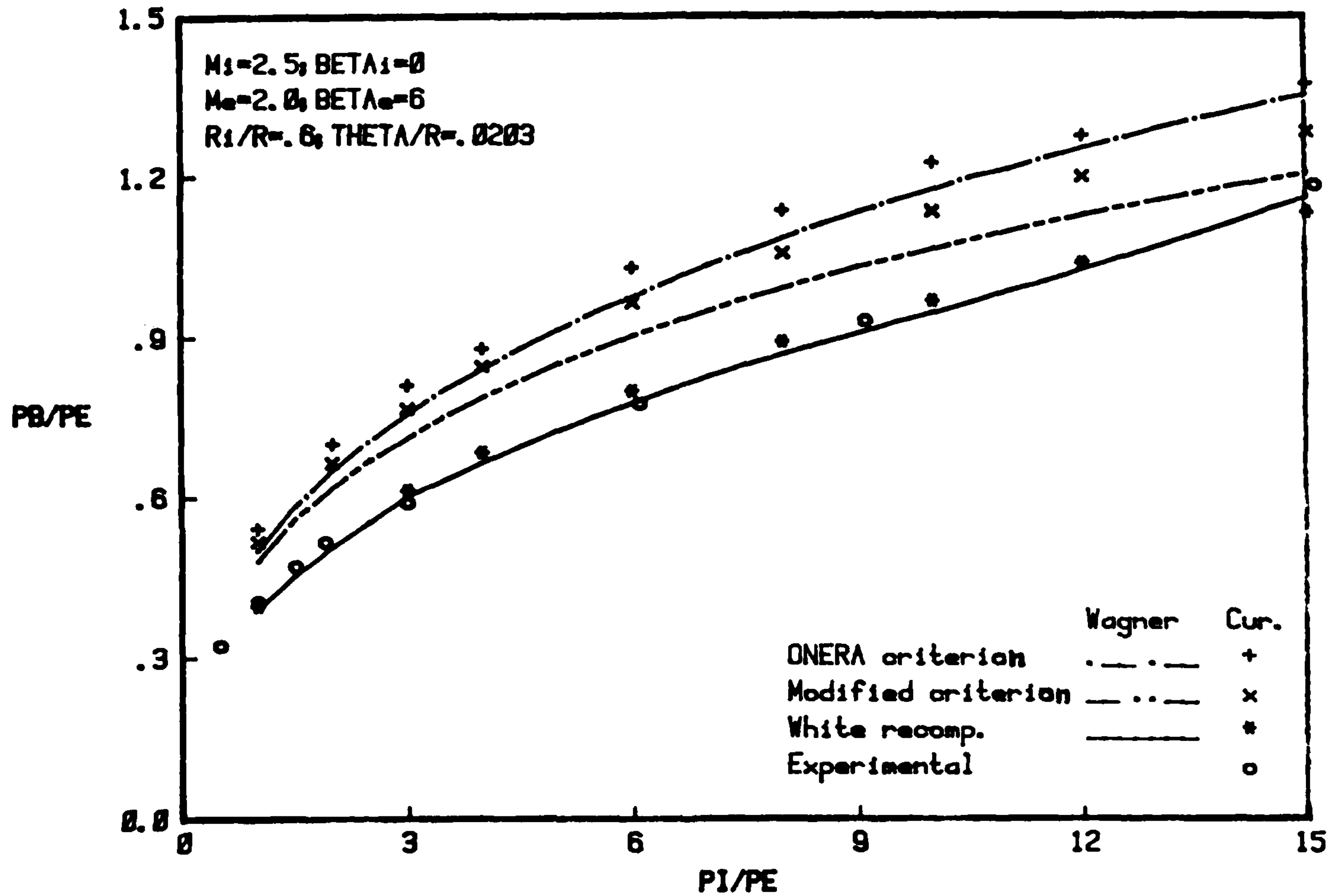

Figure 6. Comparison of current base pressure calculations with Wagner and White's calculations and experimental data from reference 19 for a conical afterbody configuration at $M_\infty = 2.0$.

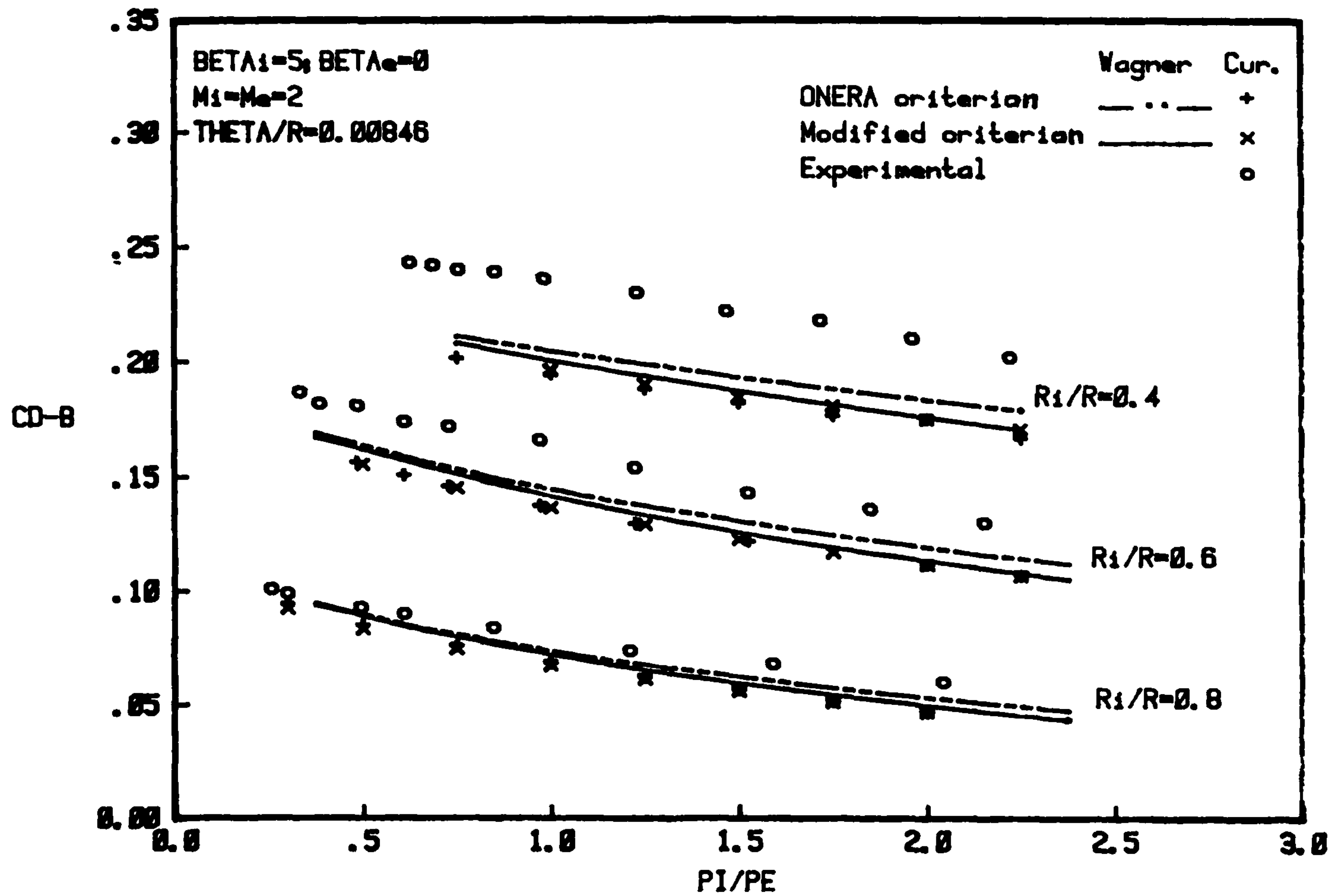

Figure 7. Comparison of current base drag coefficient calculations with Wagner and White's calculations and experimental data from reference 21 for three cylindrical afterbody configurations.

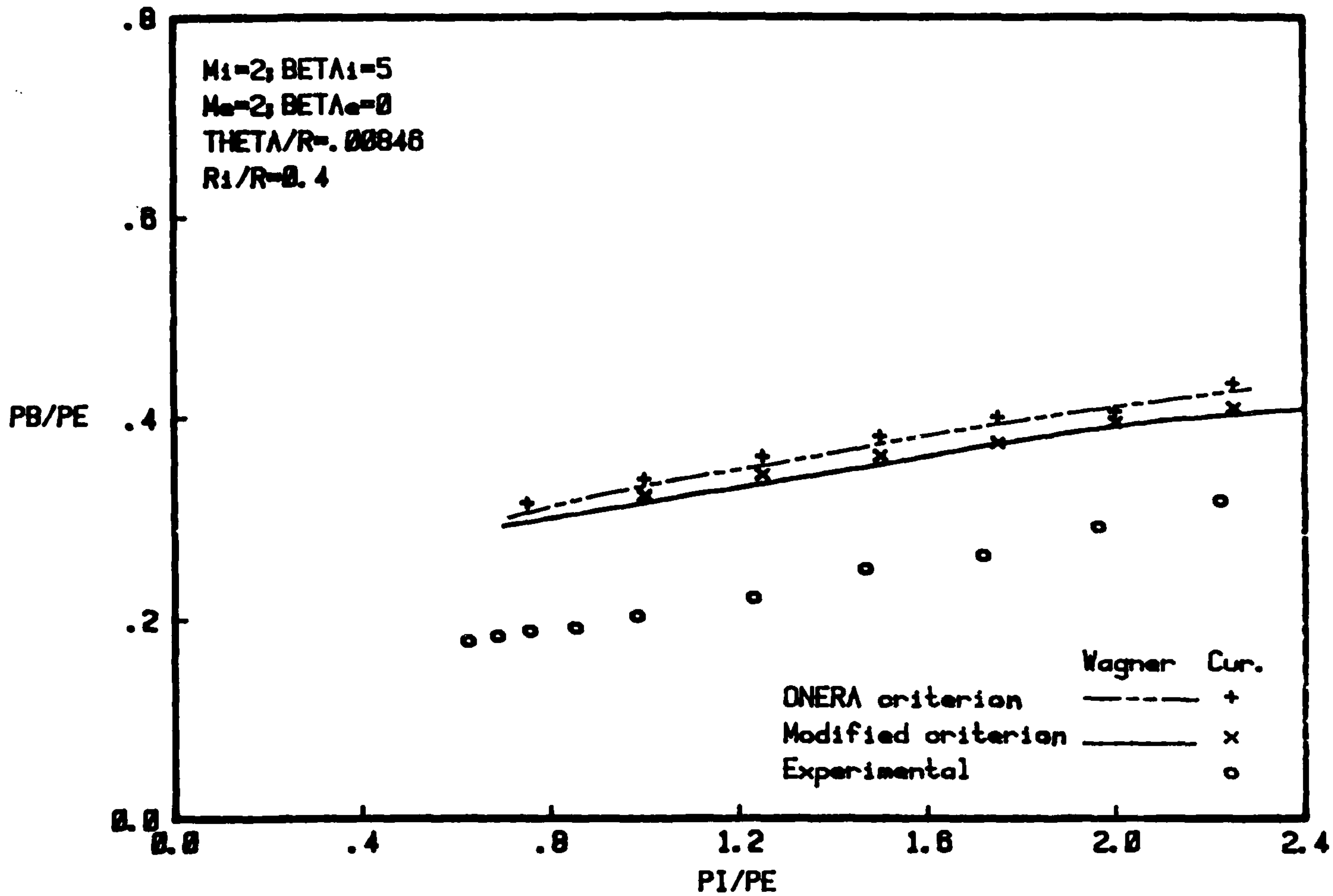

Figure 8. Comparison of current base pressure calculations with Wagner and White's calculations and experimental data from reference 21, small nozzle.

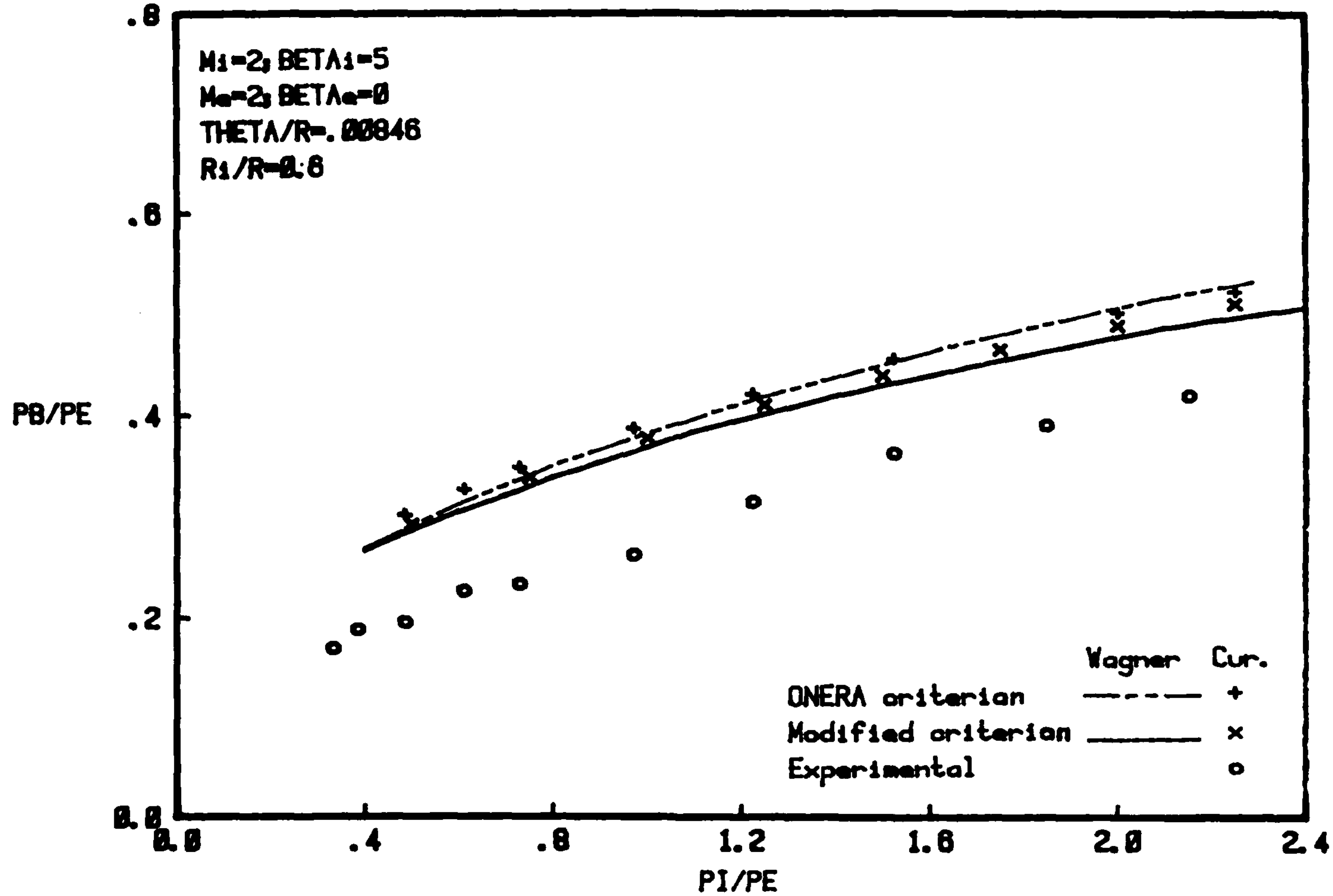

Figure 9. Comparison of current base pressure calculations with Wagner and White's calculations and experimental data from reference 21, intermediate nozzle.

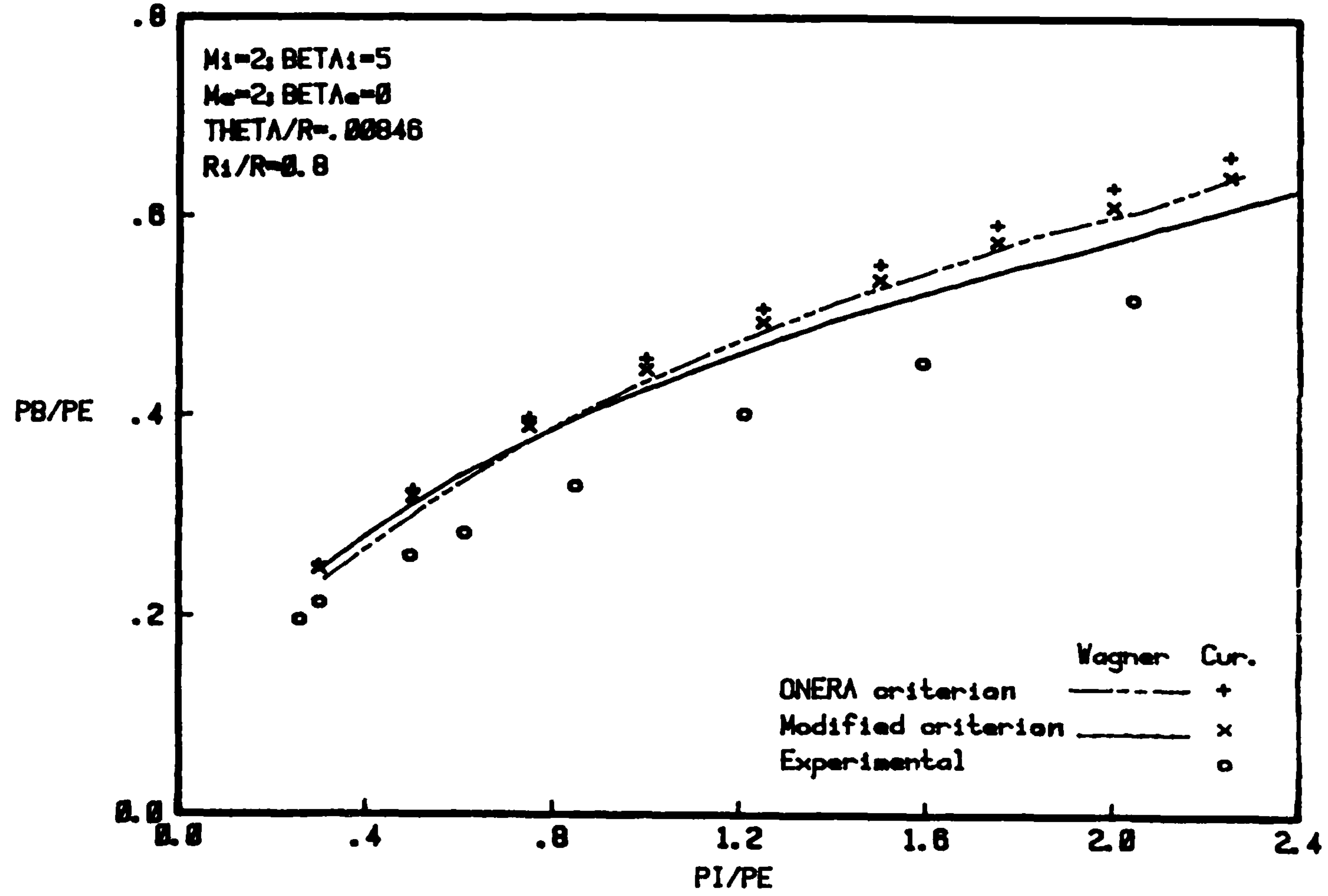

Figure 10. Comparison of current base pressure calculations with Wagner and White's calculations and experimental data from reference 21, large nozzle.

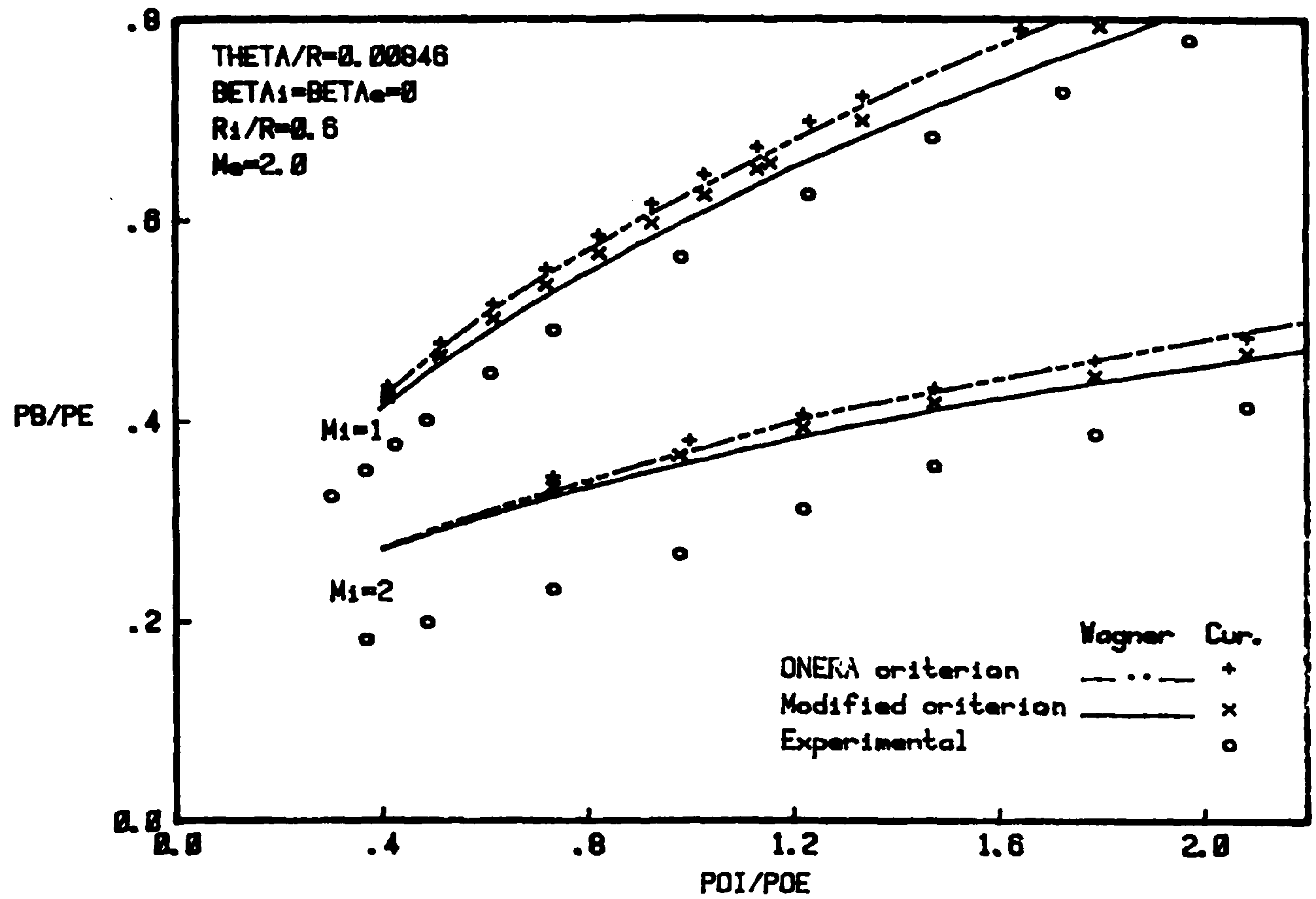

Figure 11. Comparison of current base pressure calculations with Wagner's calculations and experimental data from reference 21, sonic and mach 2.0 nozzles.

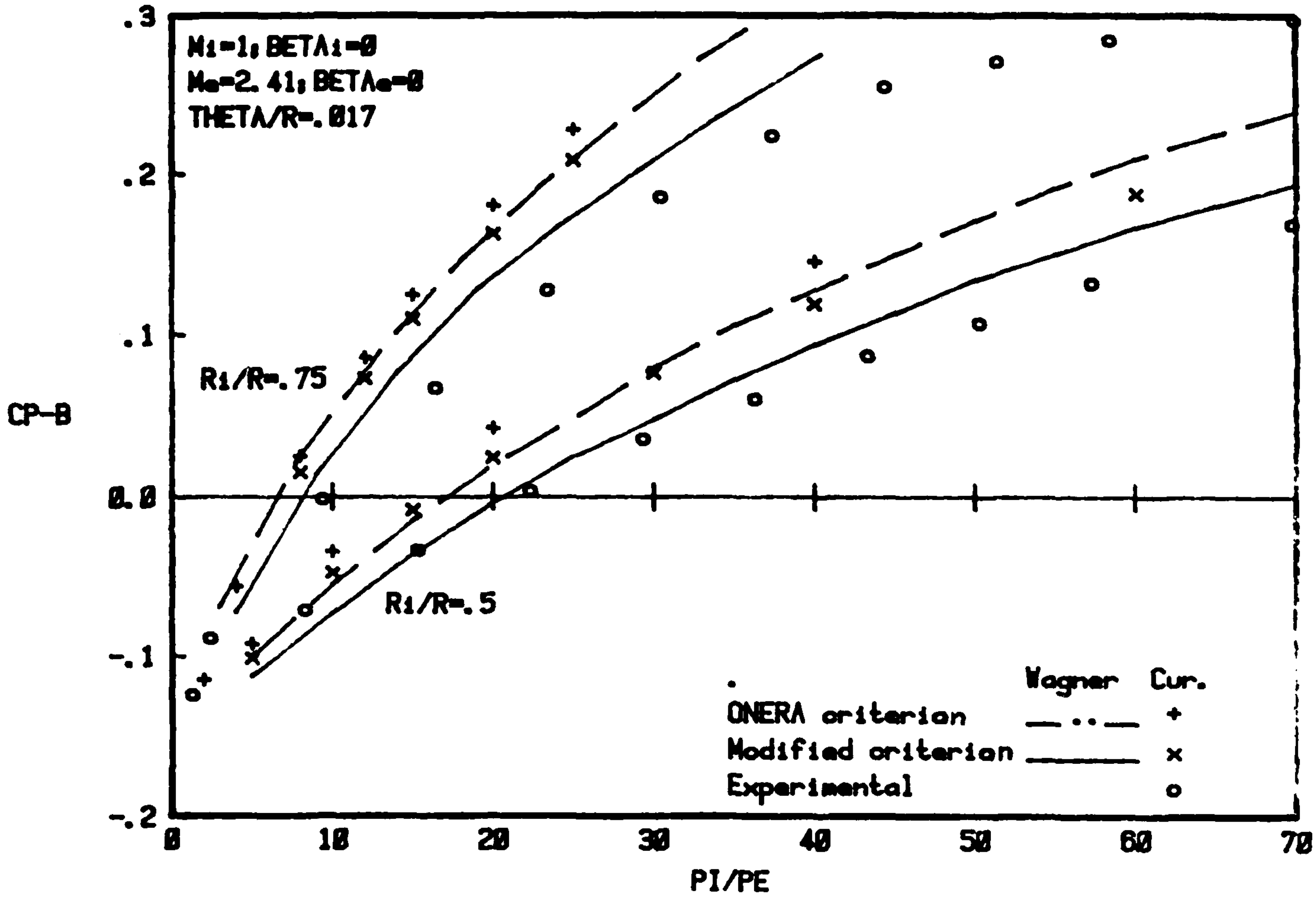

Figure 12. Comparison of current base pressure calculations with Wagner's calculations and experimental data from reference 22, radius ratios of 0.50 and 0.75.

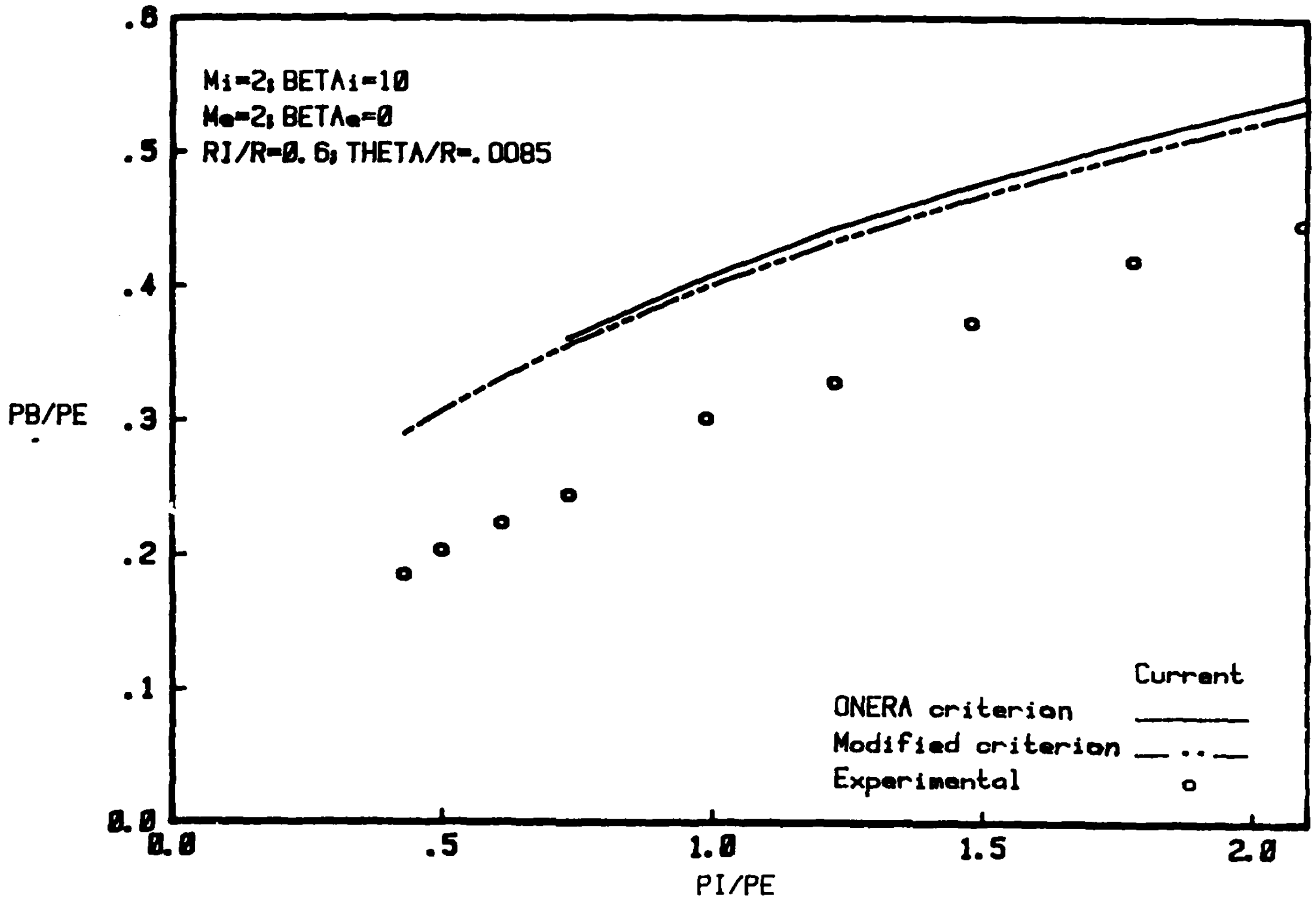

Figure 13. Comparison of calculated base pressures with experimental data from reference 21, (figure 13).

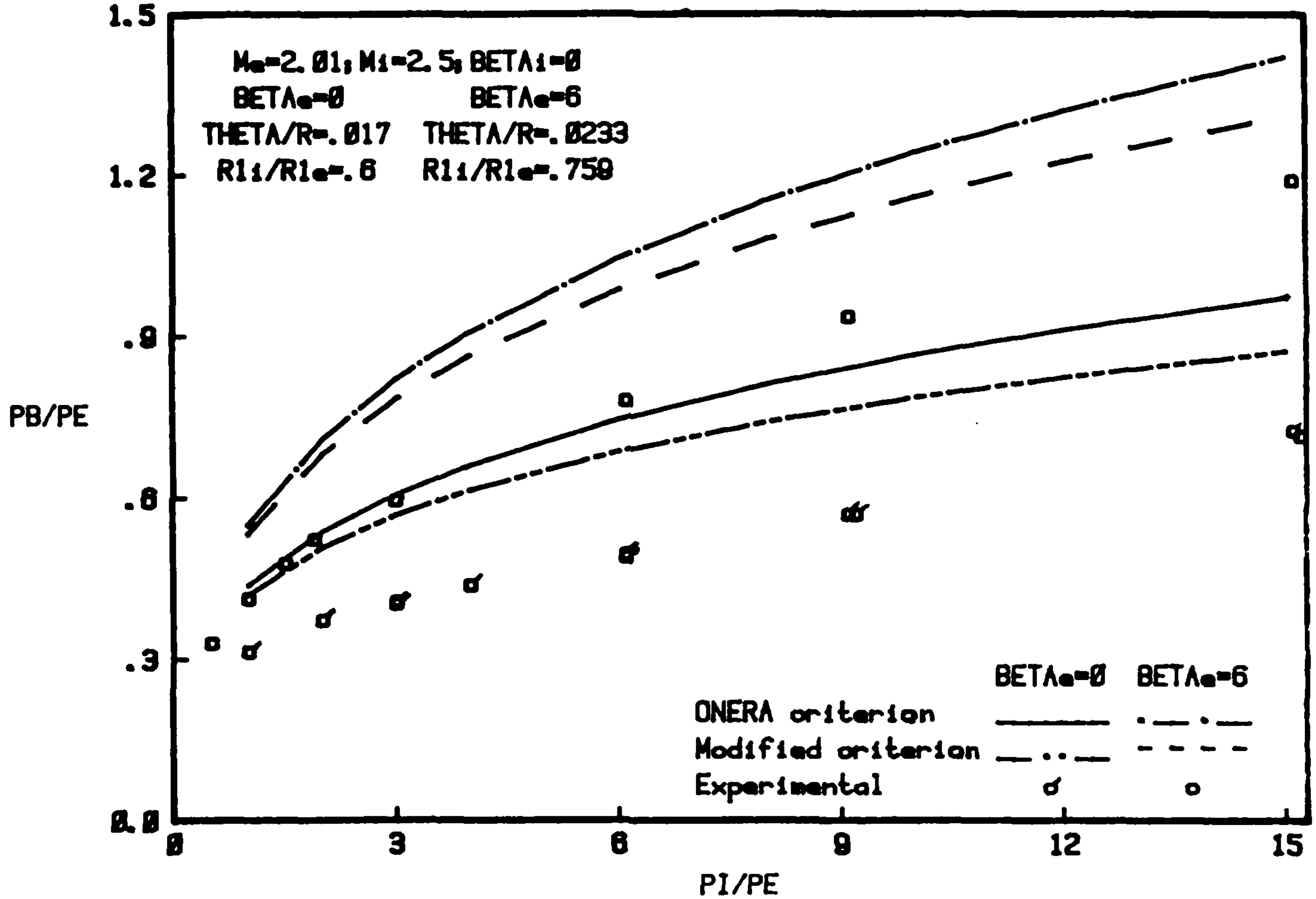

Figure 14. Comparison of calculated base pressures with experimental data from reference 19, (figure 10a), cylindrical afterbody and 6° conical boattail.

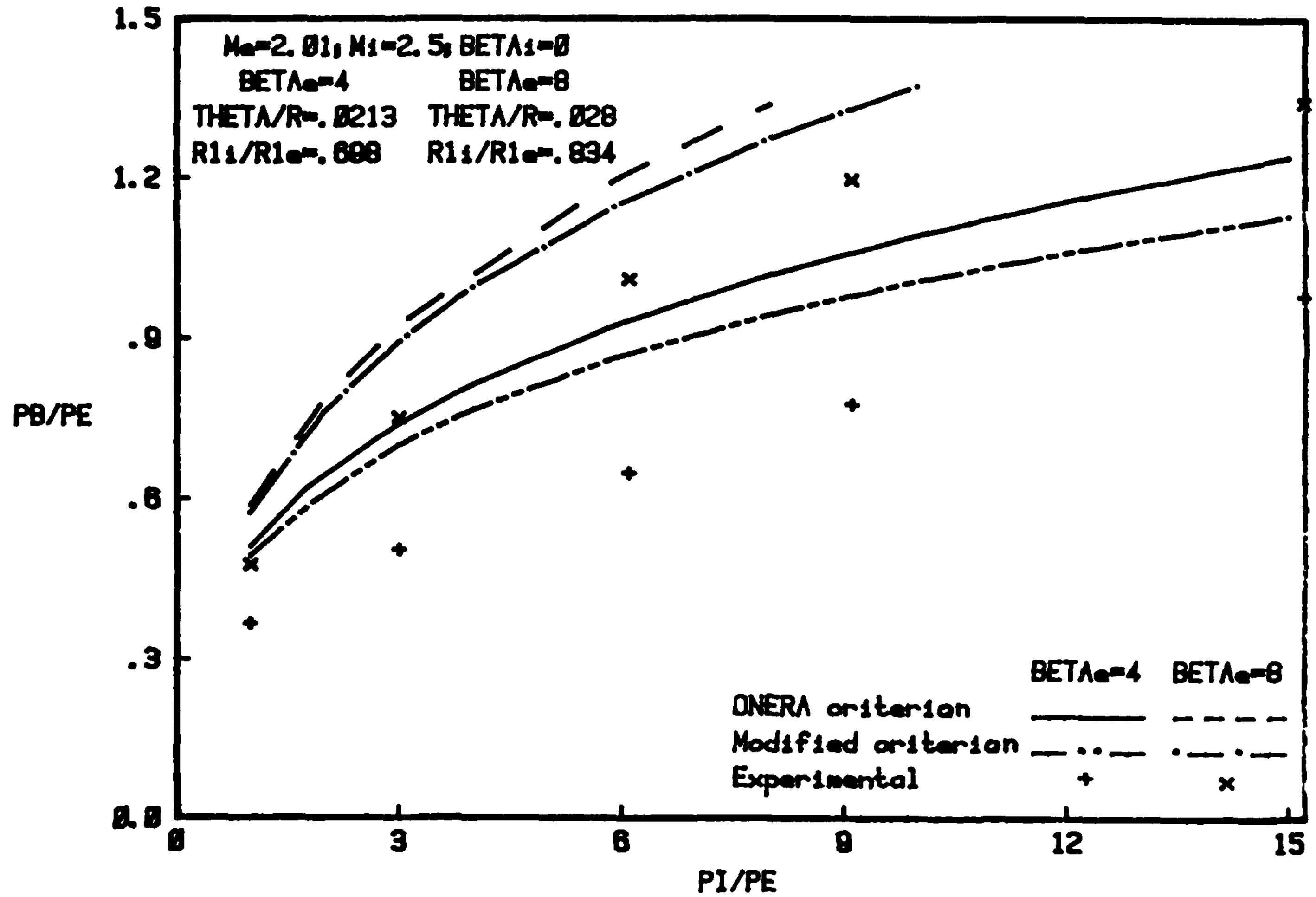

Figure 15. Comparison of calculated base pressures with experimental data from reference 19, (figure 10a), 4° and 8° conical boattails.

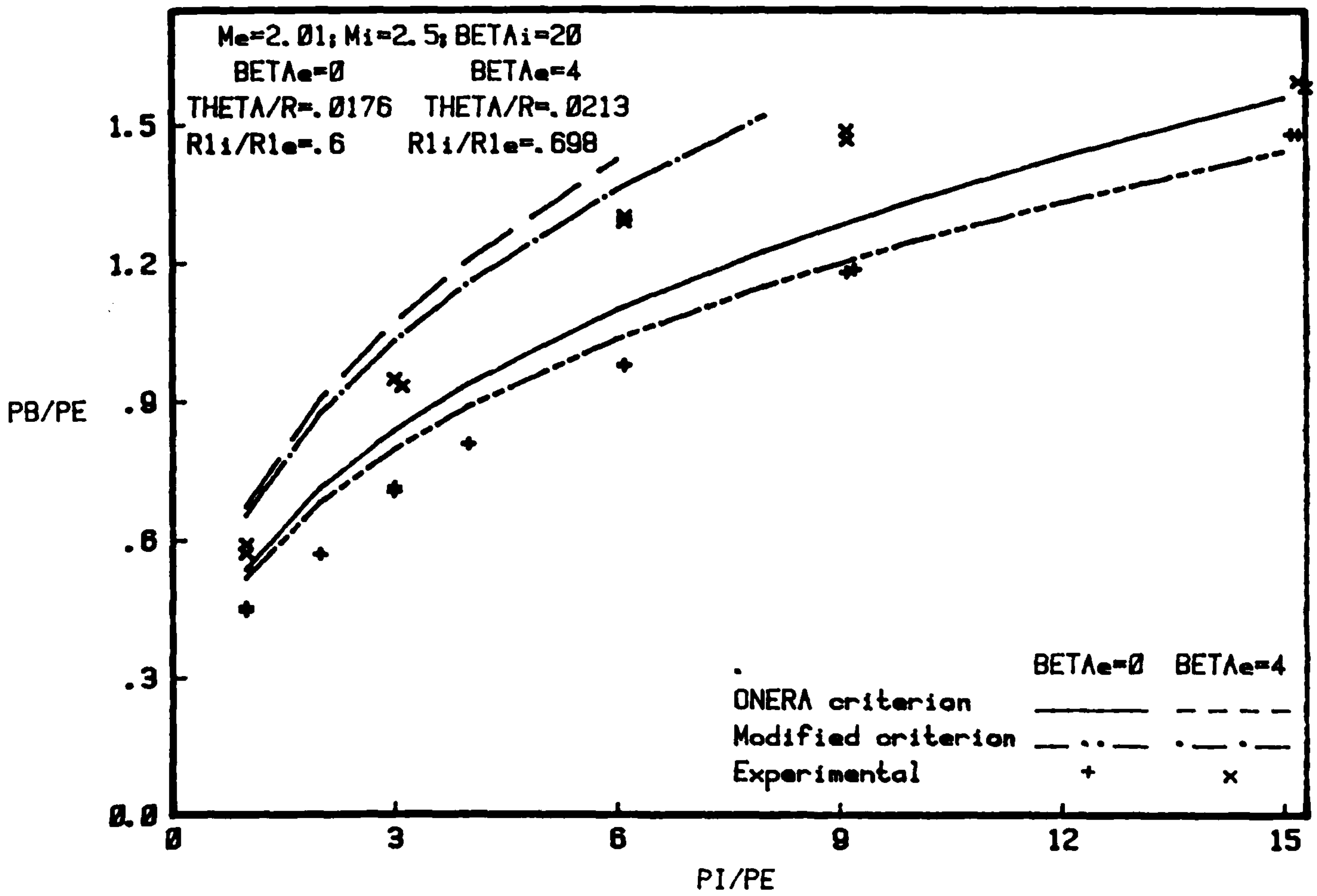

Figure 16. Comparison of calculated base pressures with experimental data from reference 19, (figure 10b), cylindrical afterbody and 4° conical boattail.

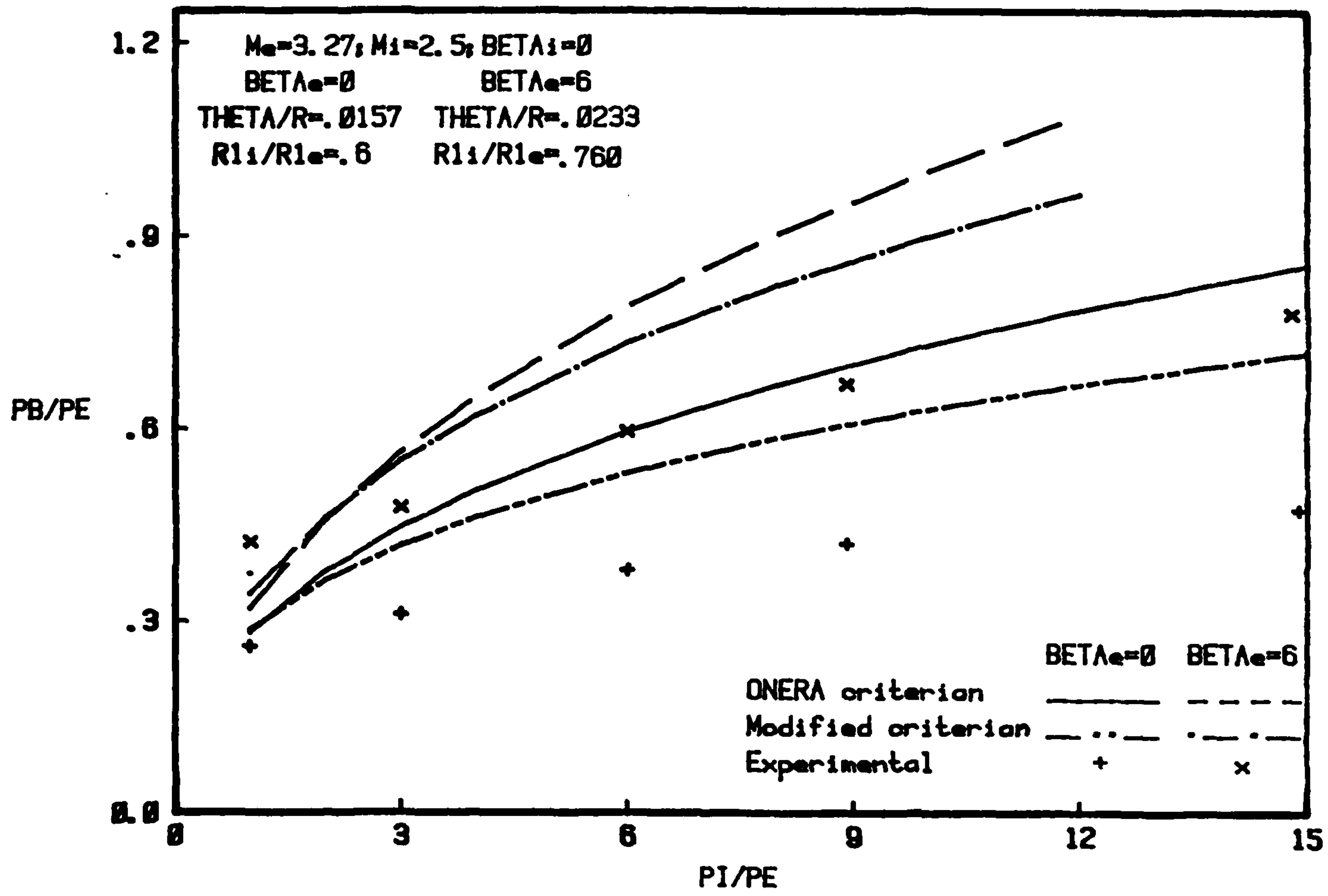

Figure 17. Comparison of calculated base pressures with experimental data from reference 19 (figure 11a), cylindrical afterbody and 6° conical boattail.

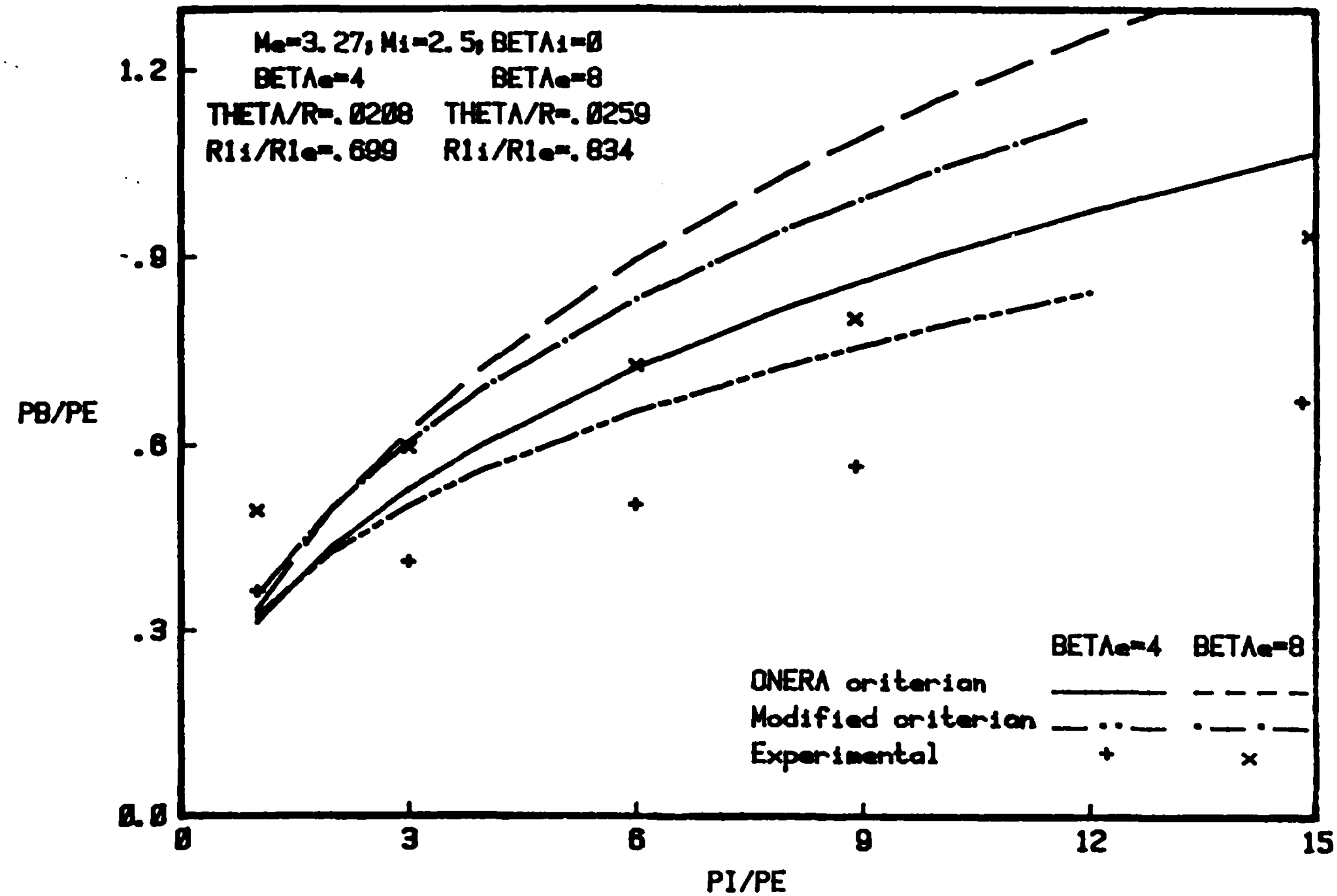

Figure 18. Comparison of calculated base pressures with experimental data from reference 19, (figure 11a), 4° and 8° conical boattails.

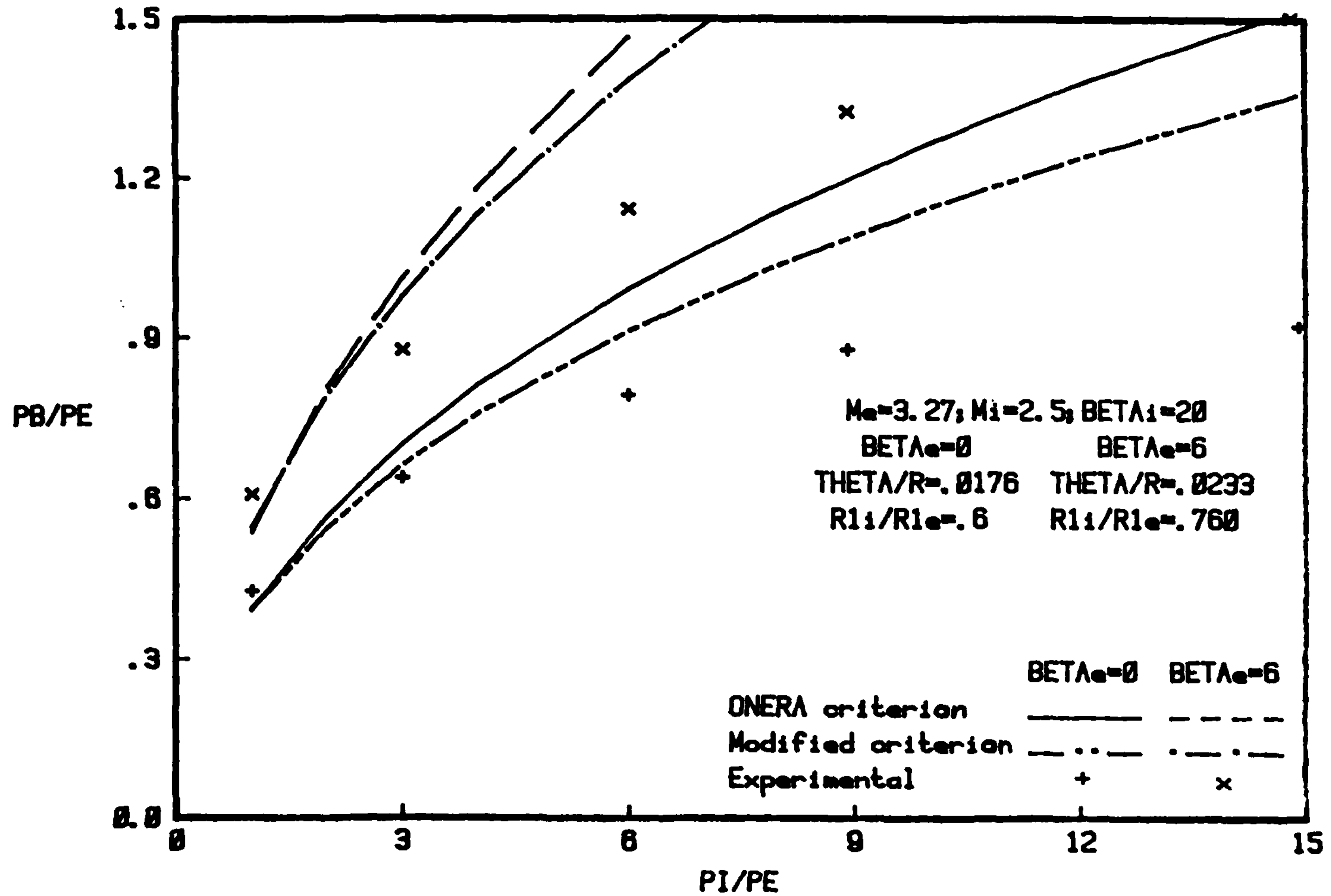

Figure 19. Comparison of calculated base pressures with experimental data from reference 19, (figure 11b), cylindrical afterbody and 6° conical boattail.

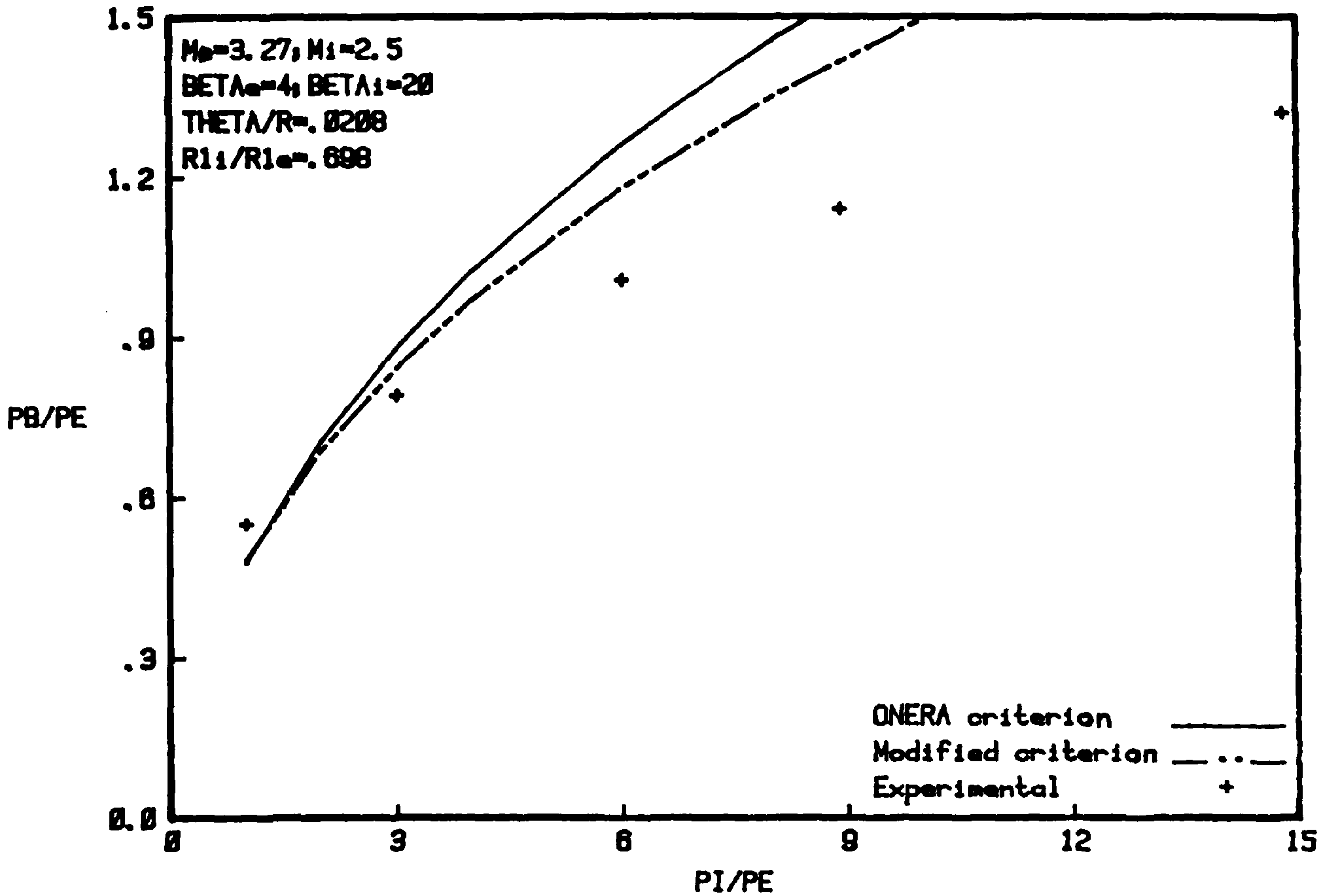

Figure 20. Comparison of calculated base pressures with experimental data from reference 19, (figure 11b), 4° conical boattail.

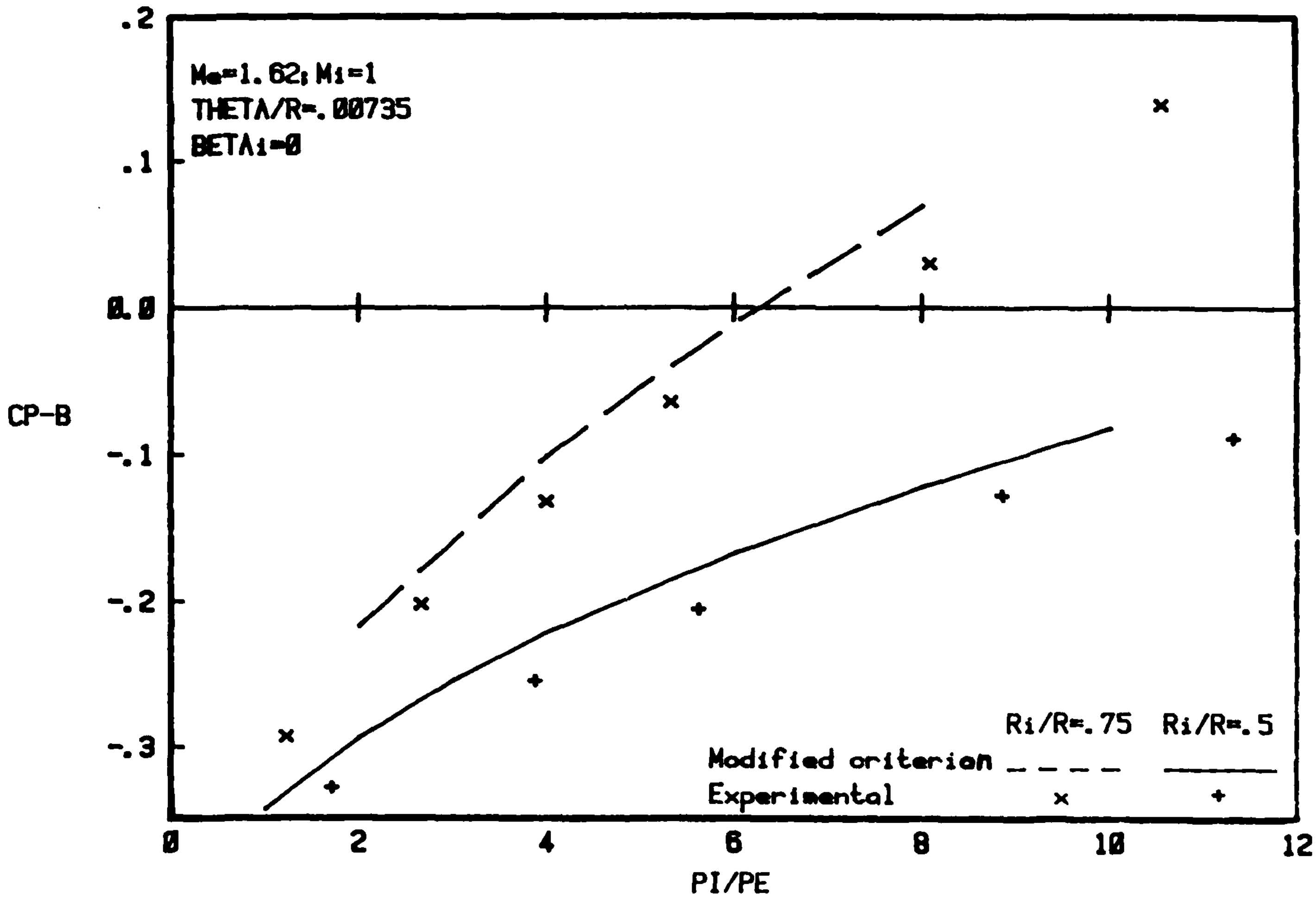

Figure 21. Comparison of calculated base pressures with experimental data from reference 22, radius ratio = 0.50 and 0.75 at $M_\infty = 1.62$.

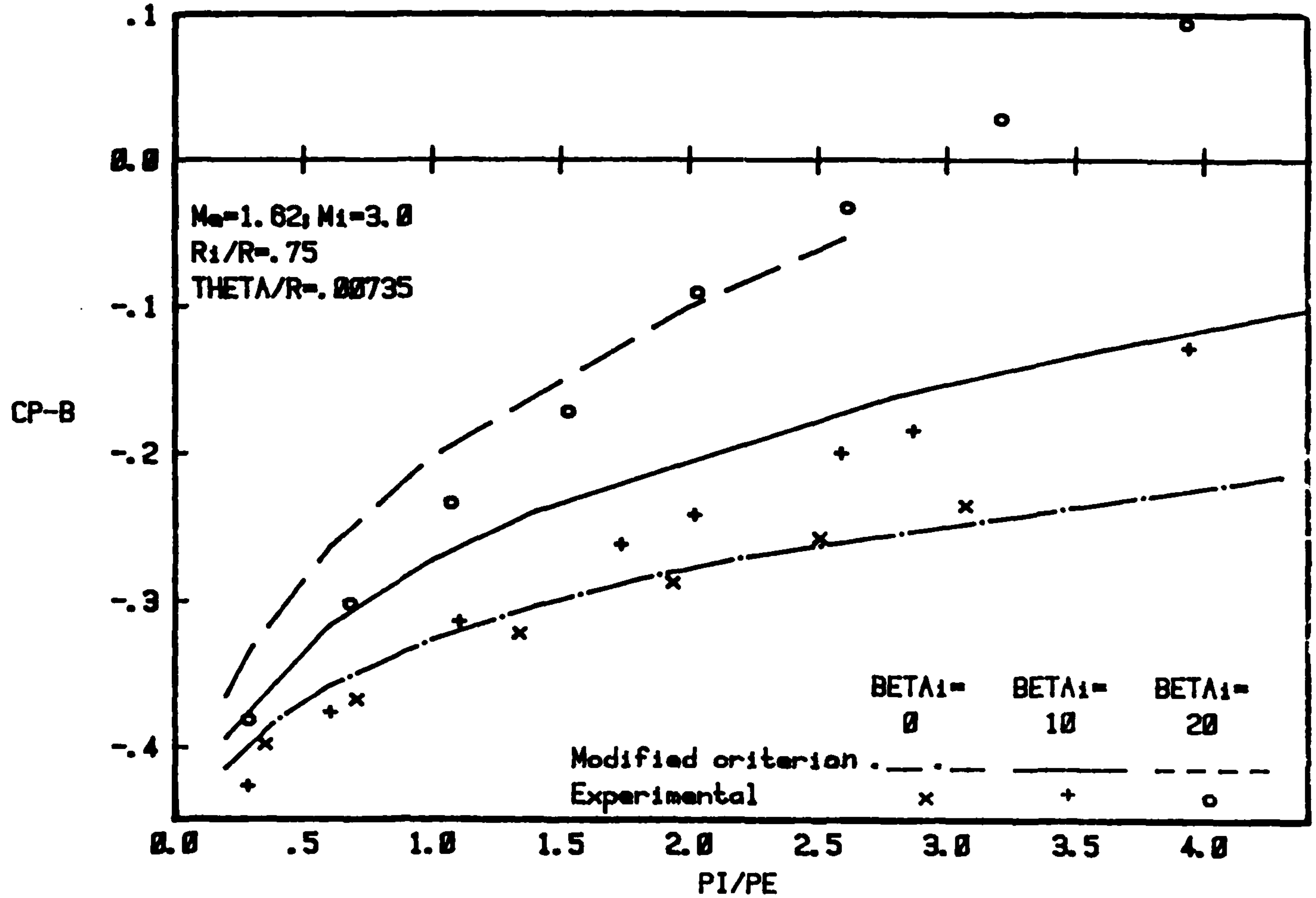

Figure 22. Comparison of calculated base pressures with experimental data from reference 22, nozzle exit angle = 0°, 10°, and 20° at M_∞ = 1.62.

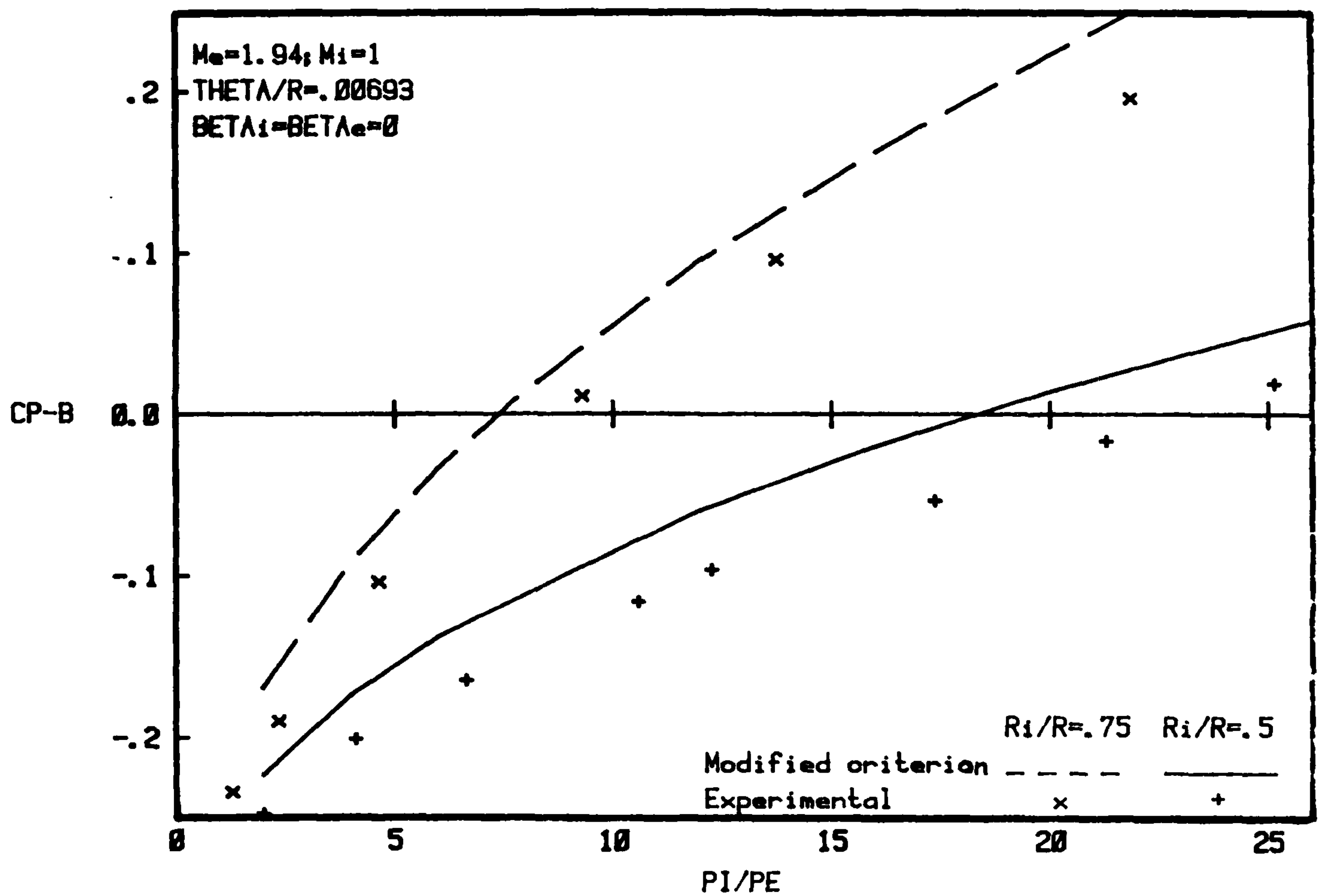

Figure 23. Comparison of calculated base pressures with experimental data from reference 22, radius ratio = 0.50 and 0.75 at $M_\infty = 1.94$.

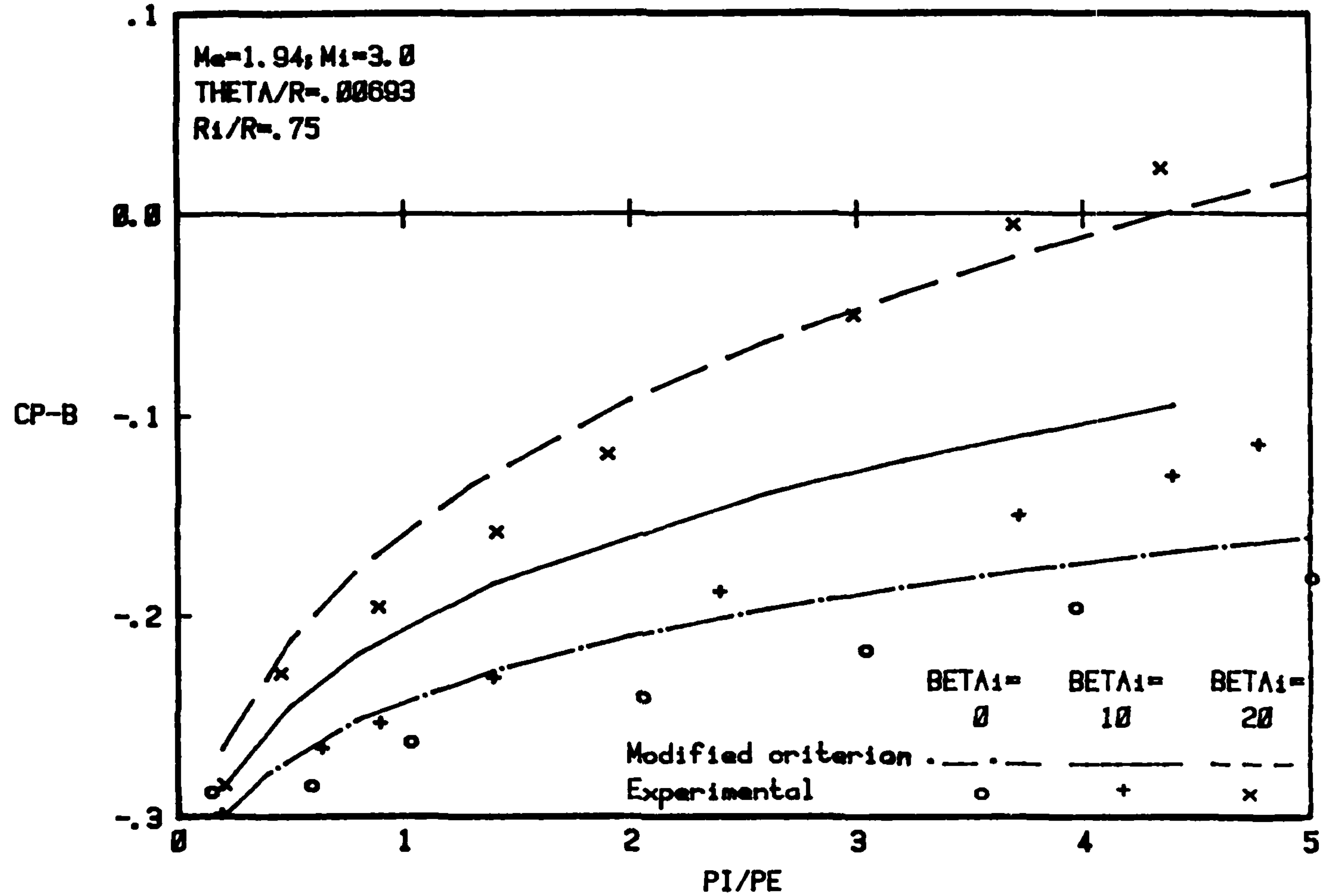

Figure 24. Comparison of calculated base pressures with experimental data from reference 22, nozzle exit angle = 0°, 10°, and 20° at M_∞ = 1.94.

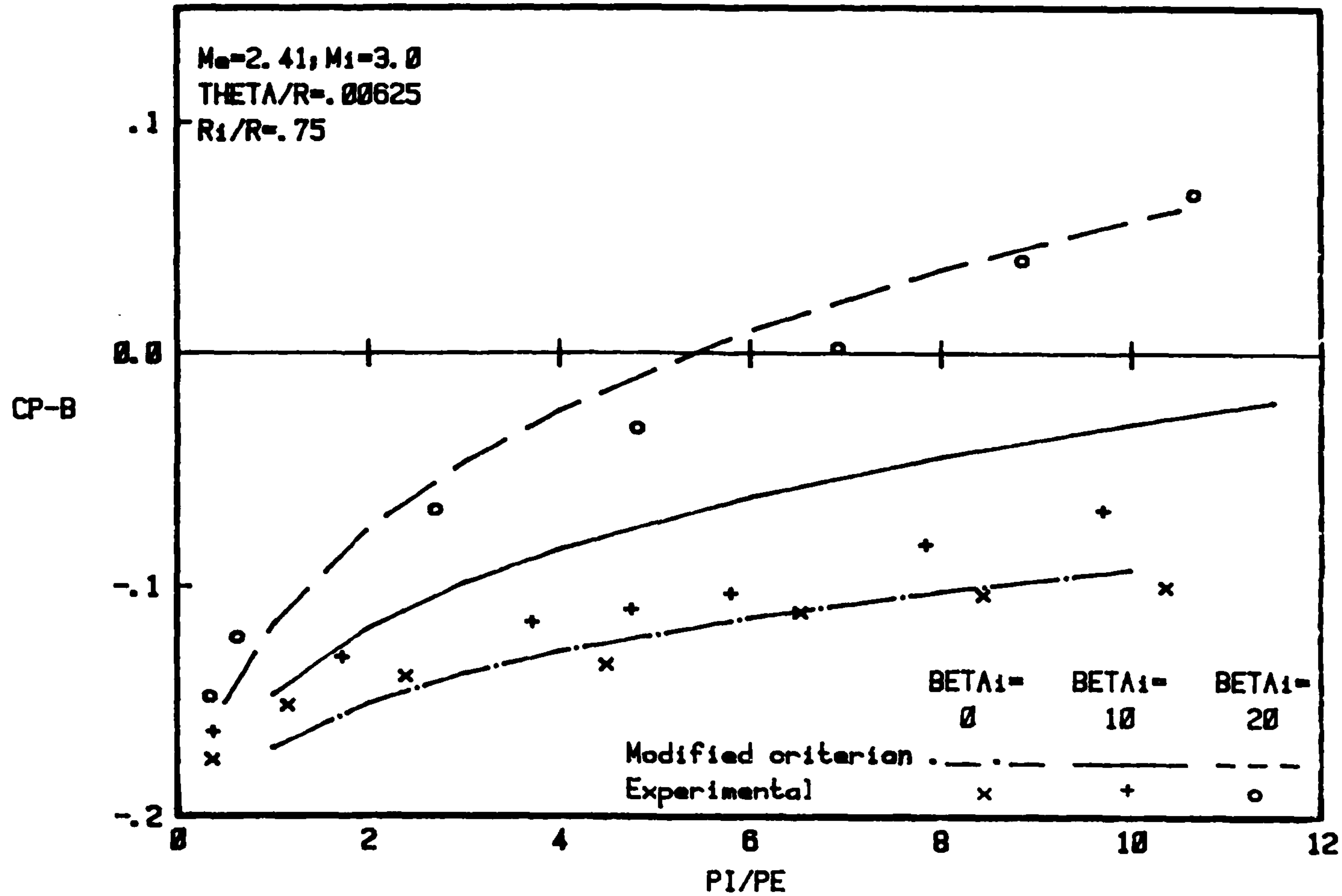

Figure 25. Comparison of calculated base pressures with experimental data from reference 22, nozzle exit angle = 0°, 10°, and 20° at $M_\infty = 2.41$.

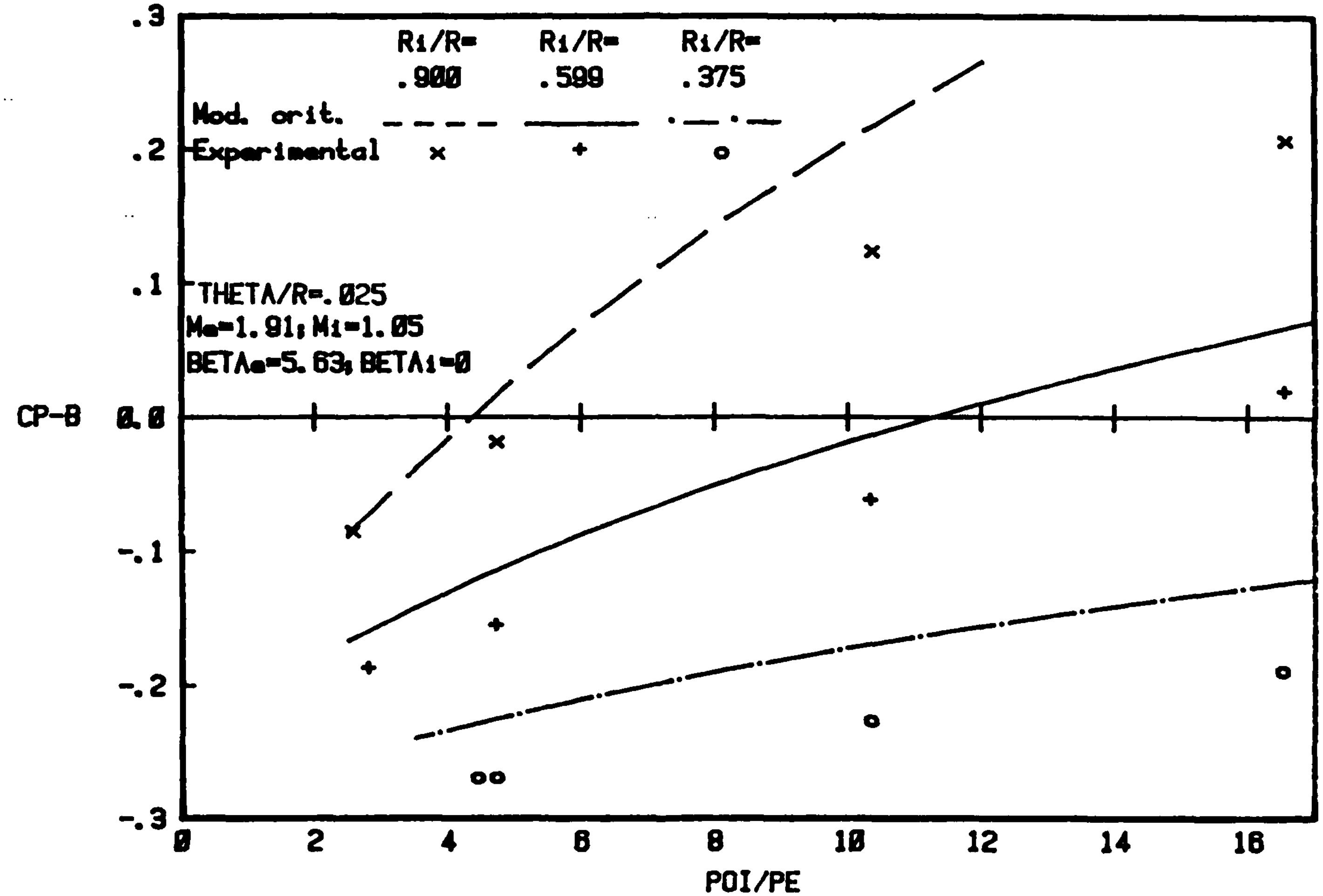

Figure 26. Comparison of calculated base pressures with experimental data from reference 23, (figure 18a), radius ratios = 0.375, 0.6, and 0.9.

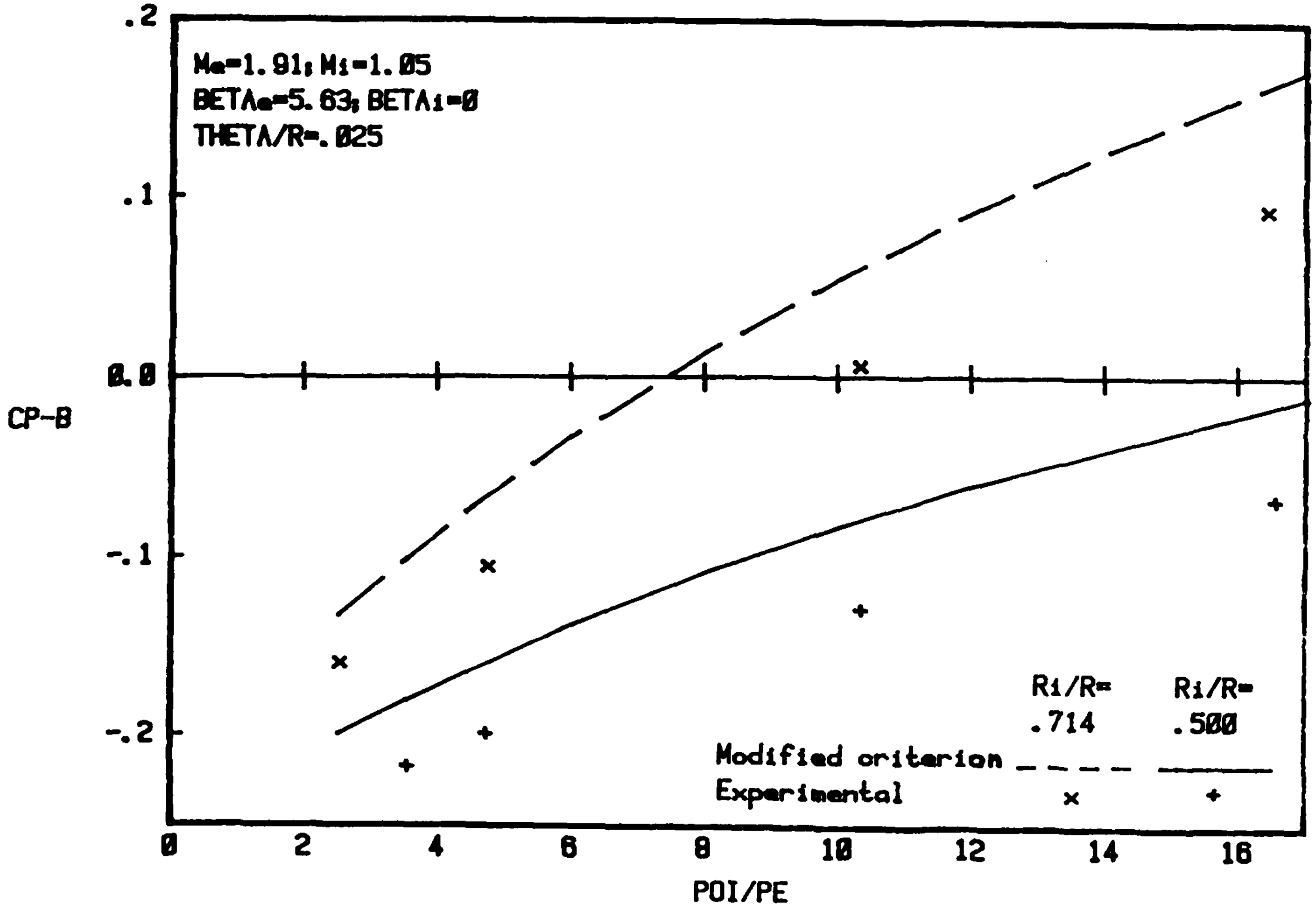

Figure 27. Comparison of calculated base pressures with experimental data from reference 23, (figure 18a), radius ratios = 0.500 and 0.714.

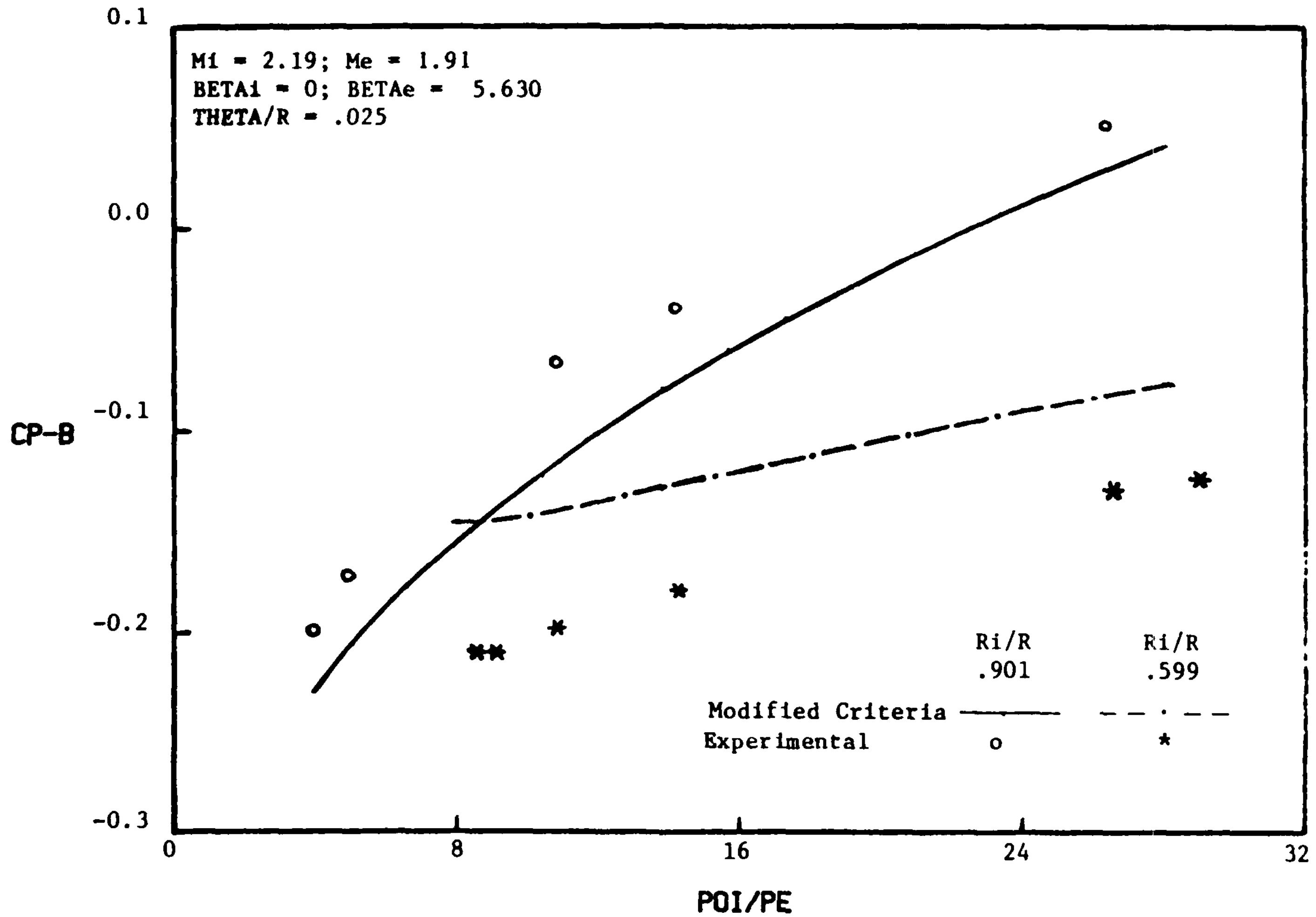

Figure 28. Comparison of calculated base pressures with experimental data from reference 23, (figure 18b), radius ratios = 0.6 and 0.9, mach 2.19 nozzle.

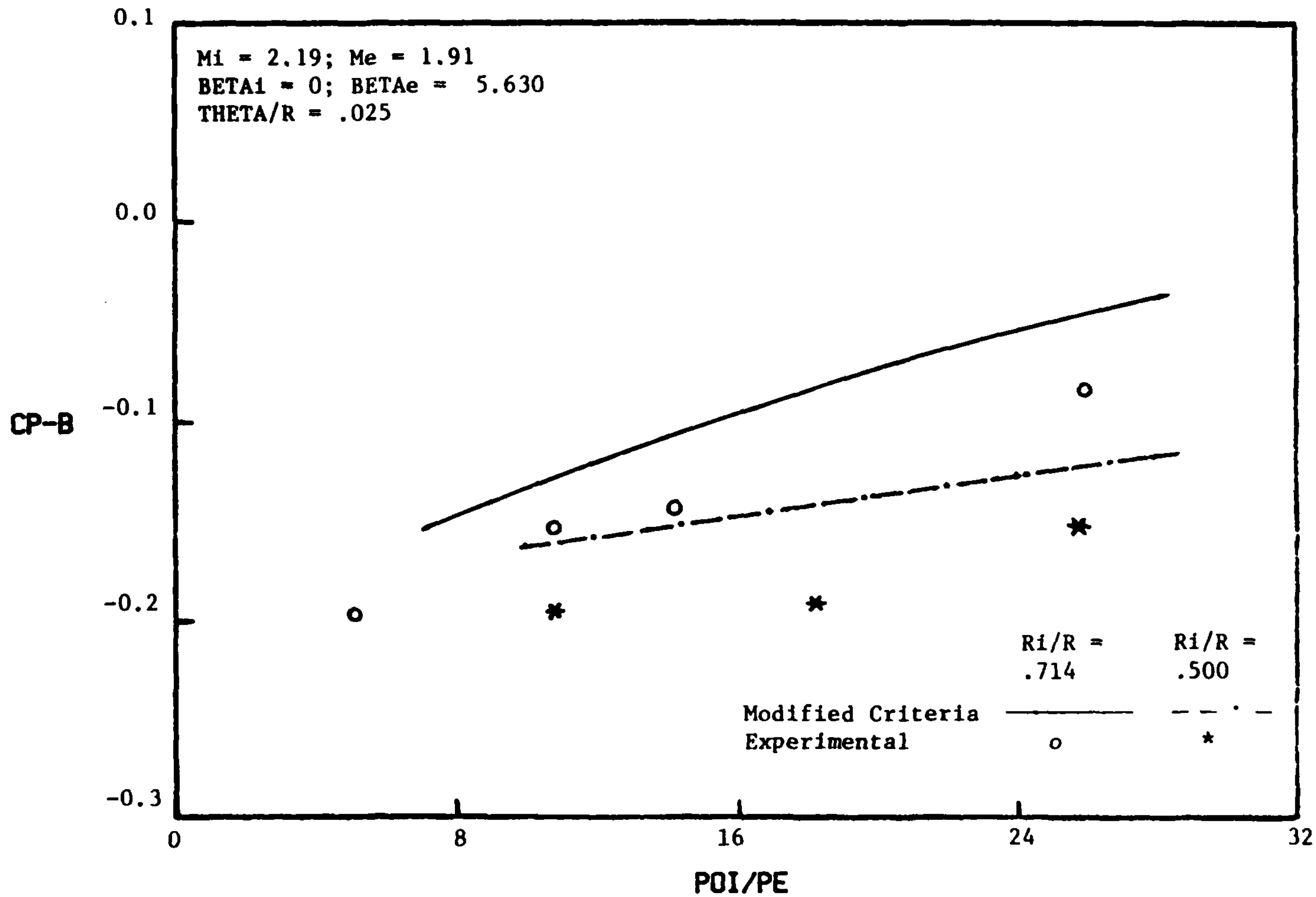

Figure 29 Comparison of calculated base pressures with experimental data from reference 23, (figure 18b), radius ratios = 0.5 and 0.714, mach 2.19 nozzle.

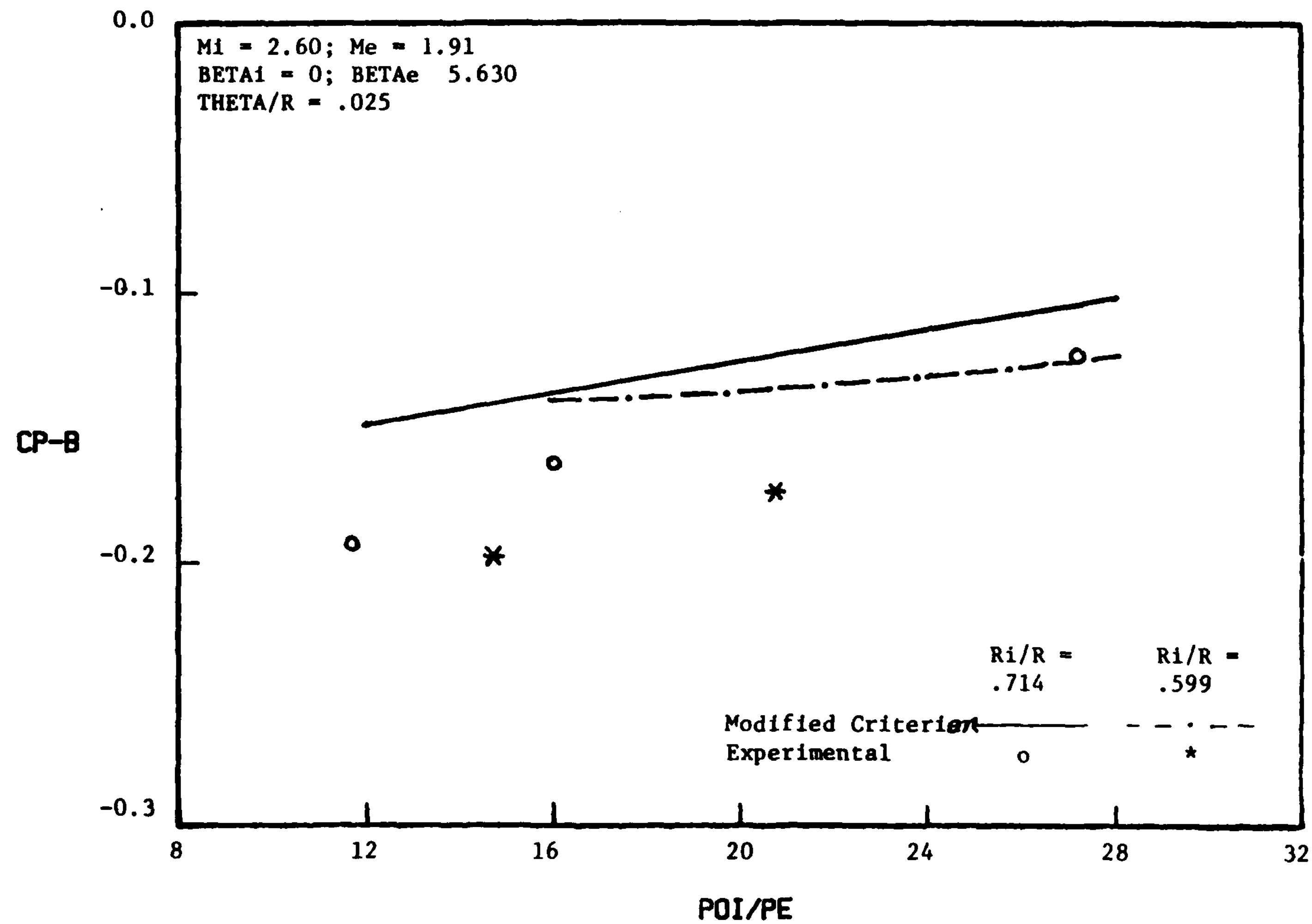

Figure 30. Comparison of calculated base pressures with experimental data from reference 23, (figure 18c), radius ratios = 0.6 and 0.714, mach 2.60 nozzle.

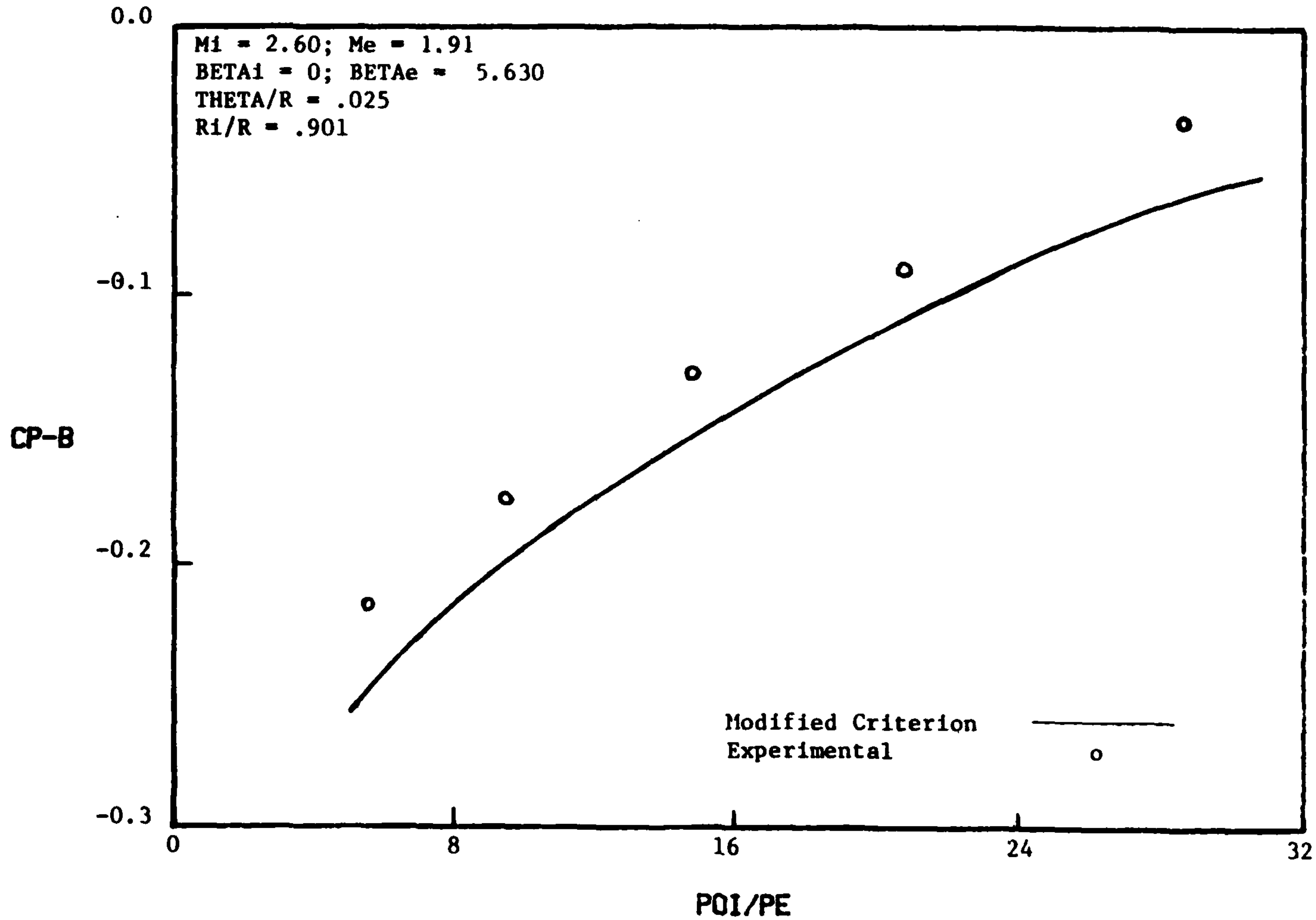

Figure 31. Comparison of calculated base pressures with experimental data from reference 23, (figure 18c), radius ratio = 0.9 and mach 2.60 nozzle.

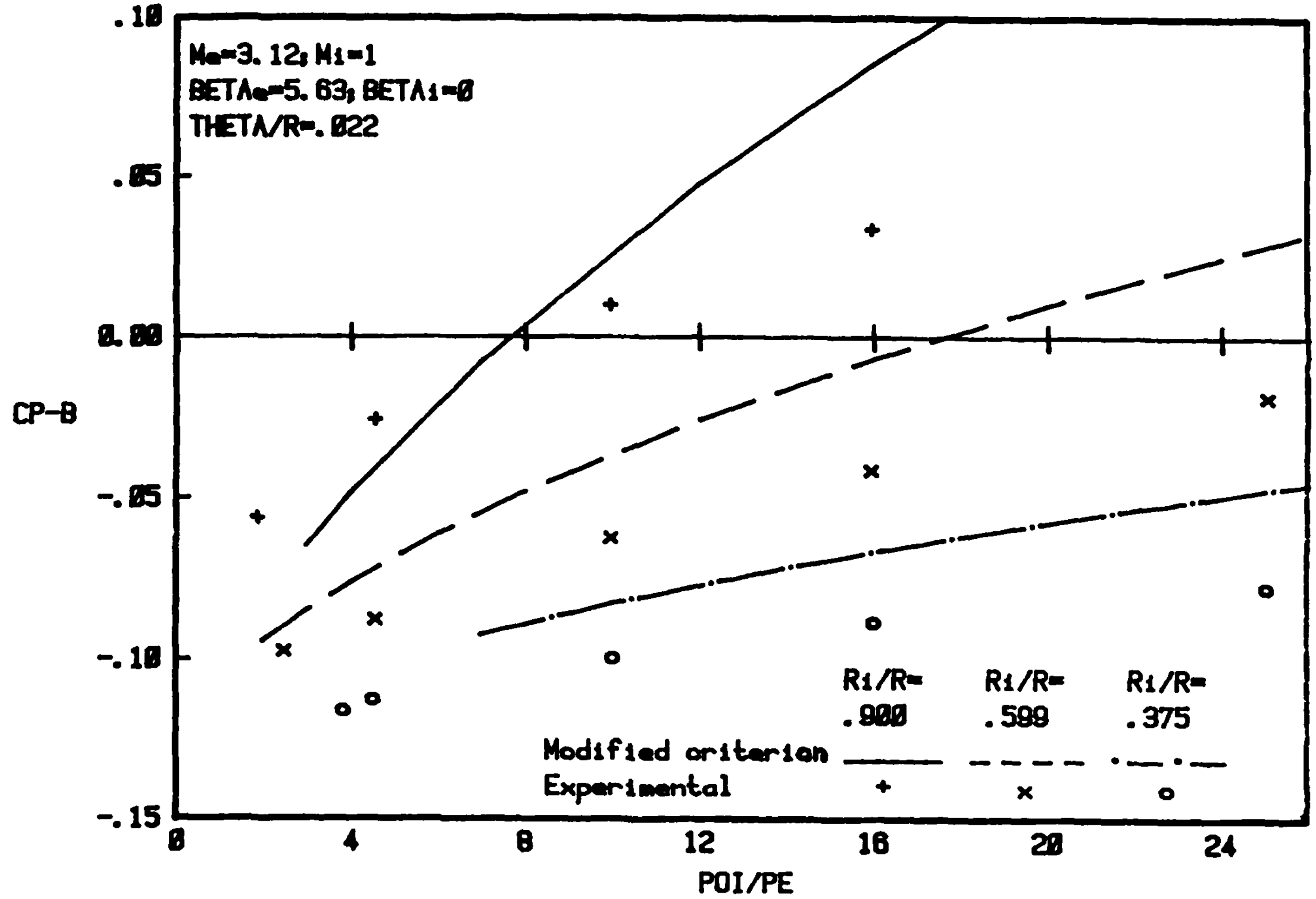

Figure 32. Comparison of calculated base pressures with experimental data from reference 23, (figure 19a), radius ratios = 0.375, 0.6, and 0.9.

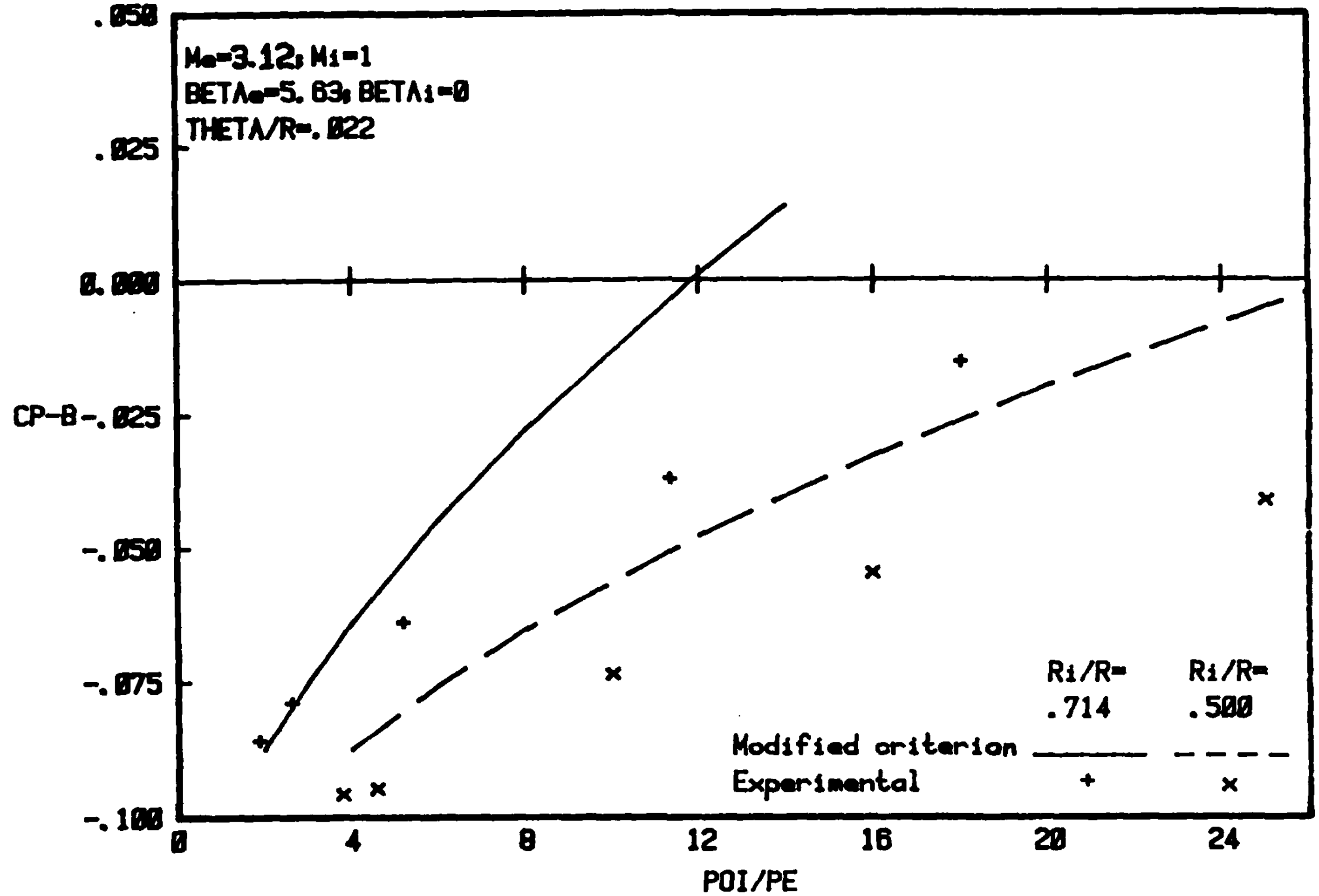

Figure 33. Comparison of calculated base pressures with experimental data from reference 23, (figure 19a), radius ratios = 0.5 and 0.714.

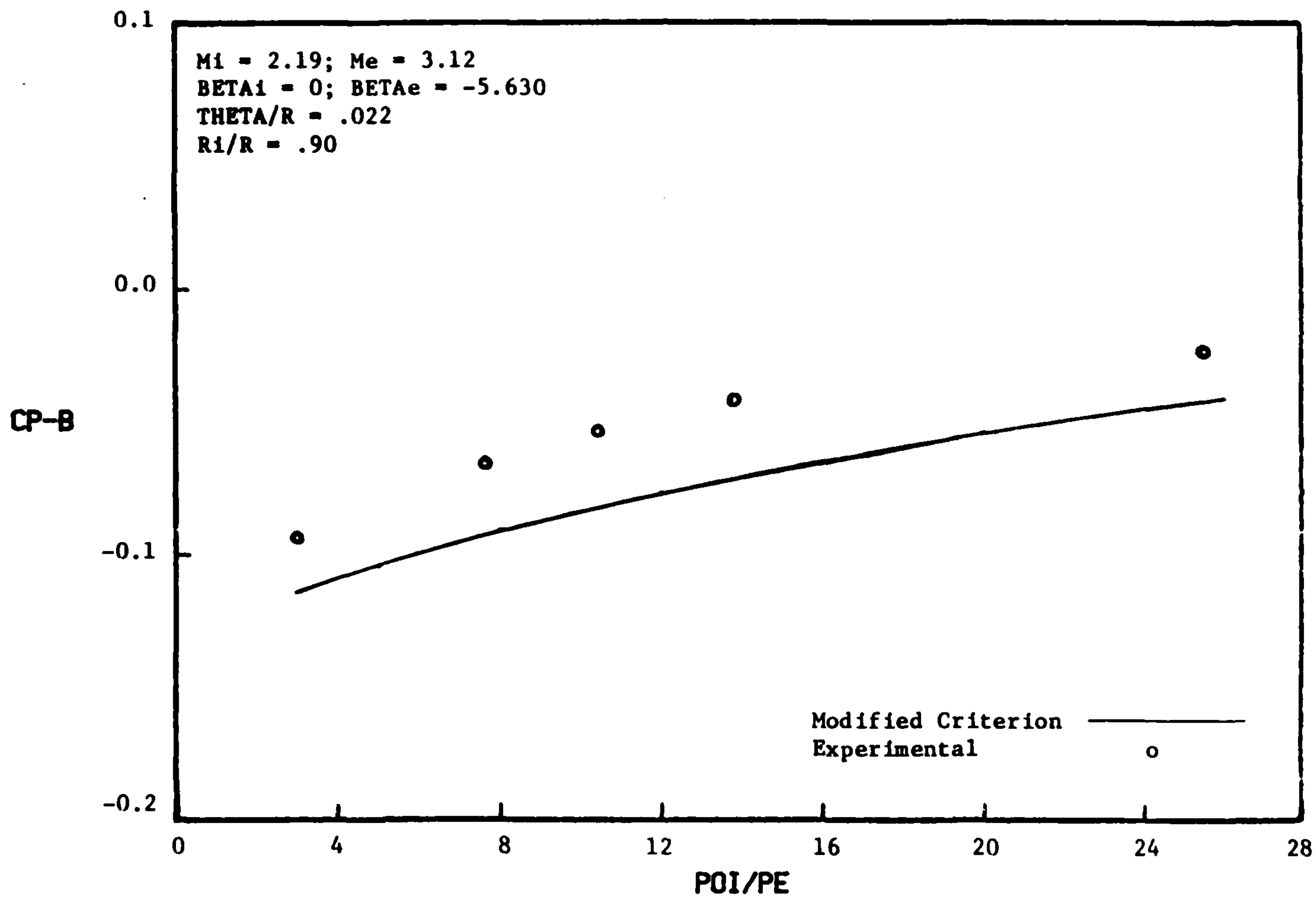

Figure 34. Comparison of calculated base pressures with experimental data from reference 23, (figure 19b), boattail angle = 5.63 degrees.

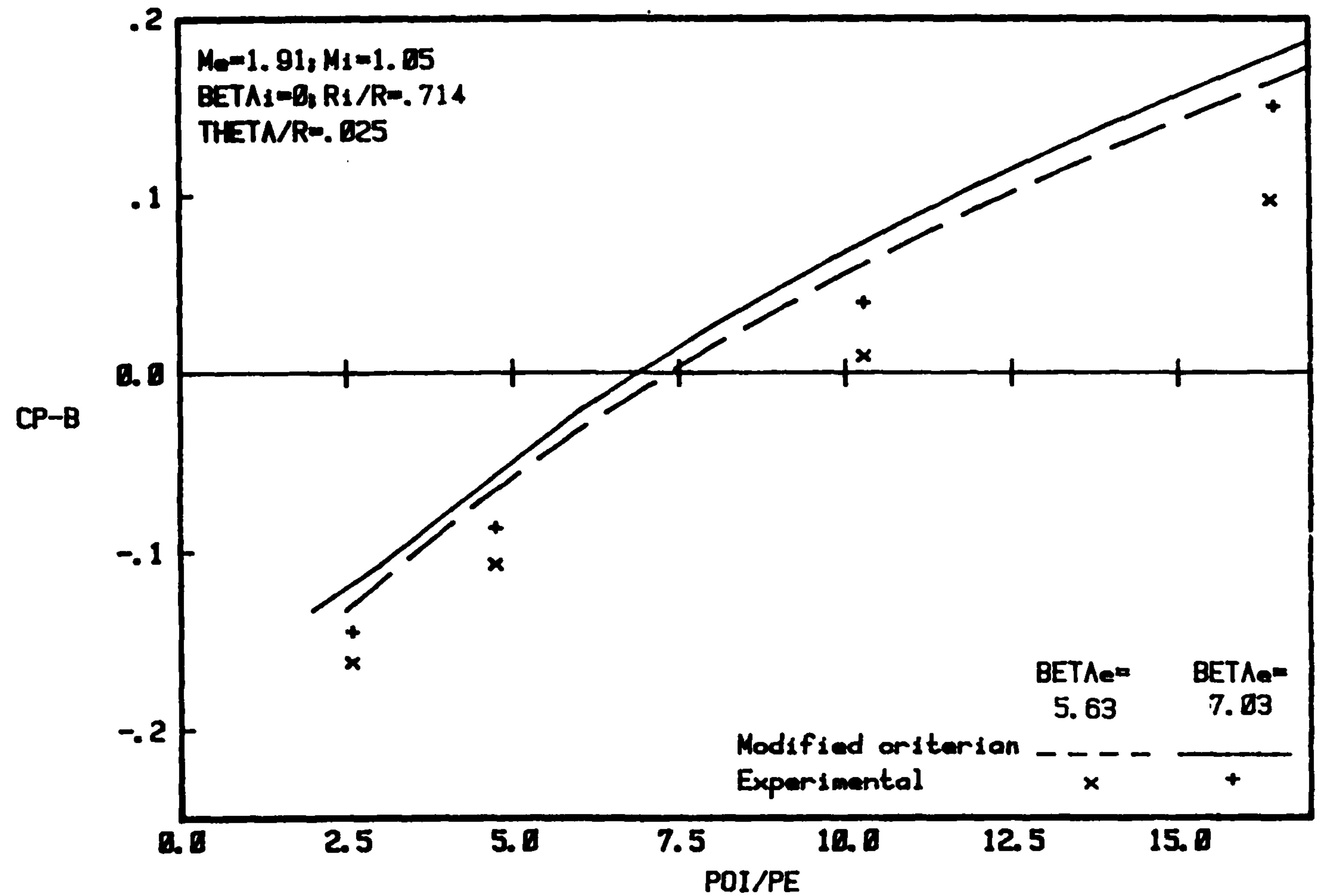

Figure 35. Comparison of calculated base pressures with experimental data from reference 23, (figure 23a), boattail angles = 5.63 and 7.03 degrees.

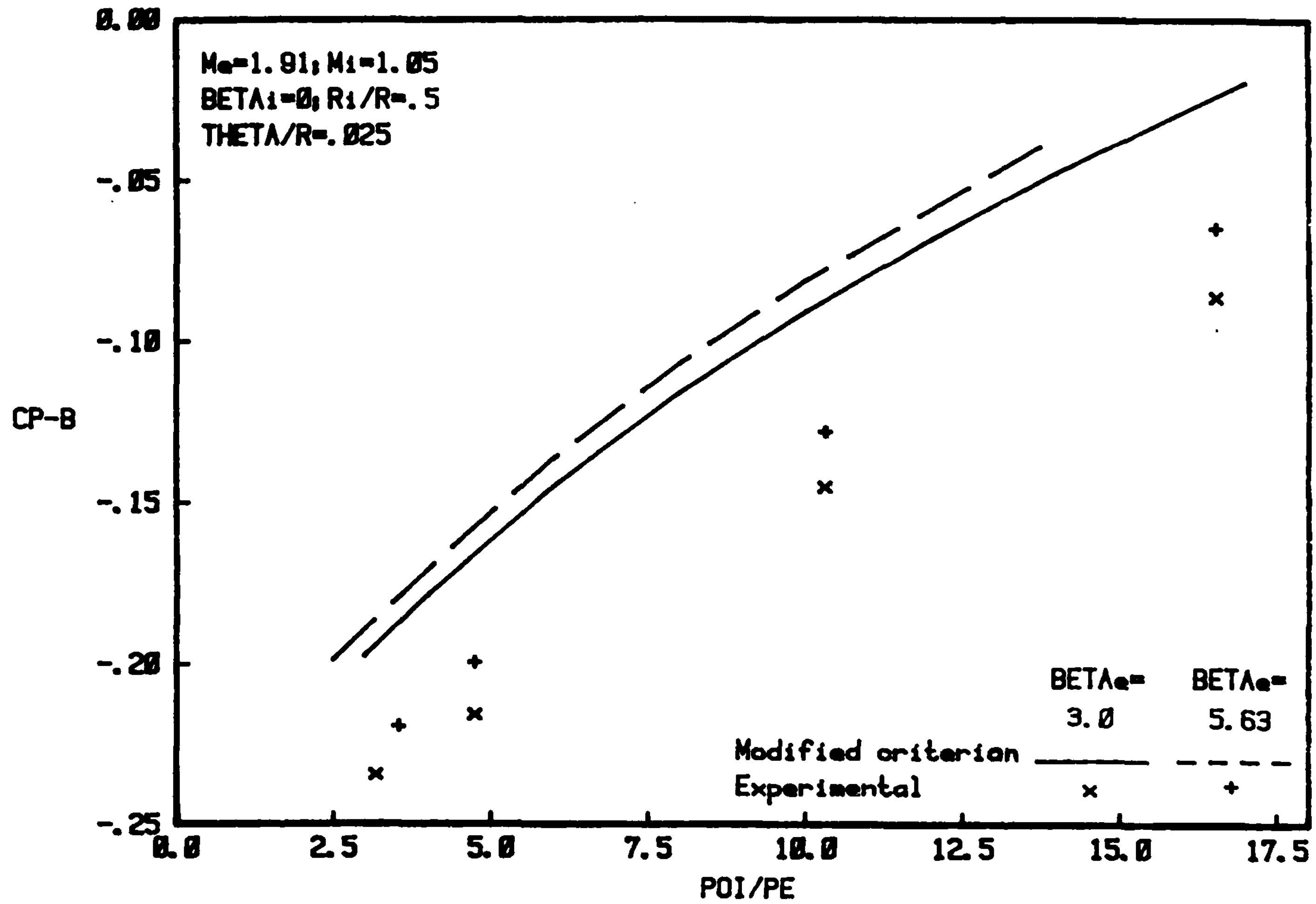

Figure 36. Comparison of calculated base pressures with experimental data from reference 23, (figure 23a), boattail angles = 3.00 and 5.63 degrees.

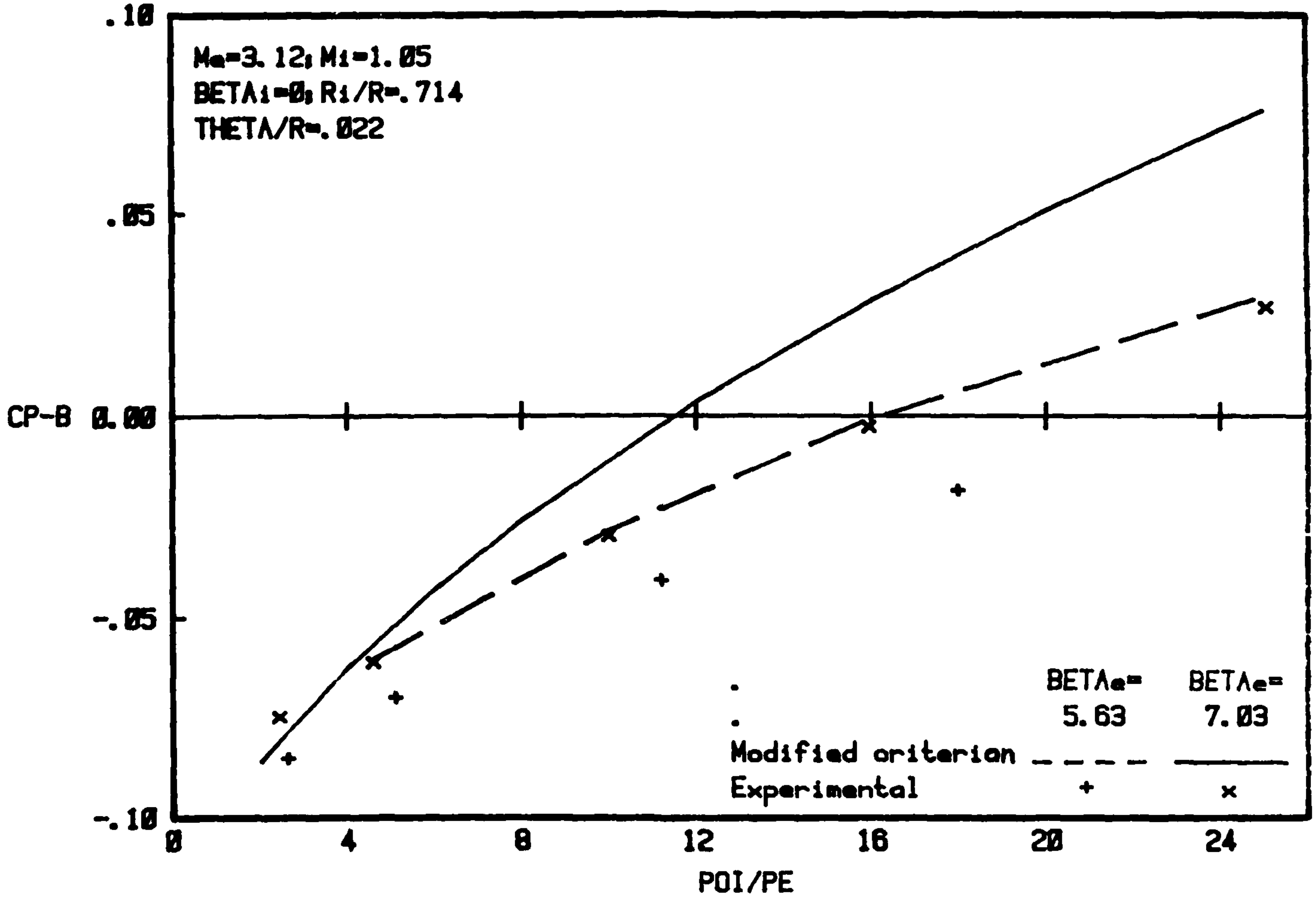

Figure 37. Comparison of calculated base pressures with experimental data from reference 23, (figure 24a), boattail angles = 5.63 and 7.03 degrees.

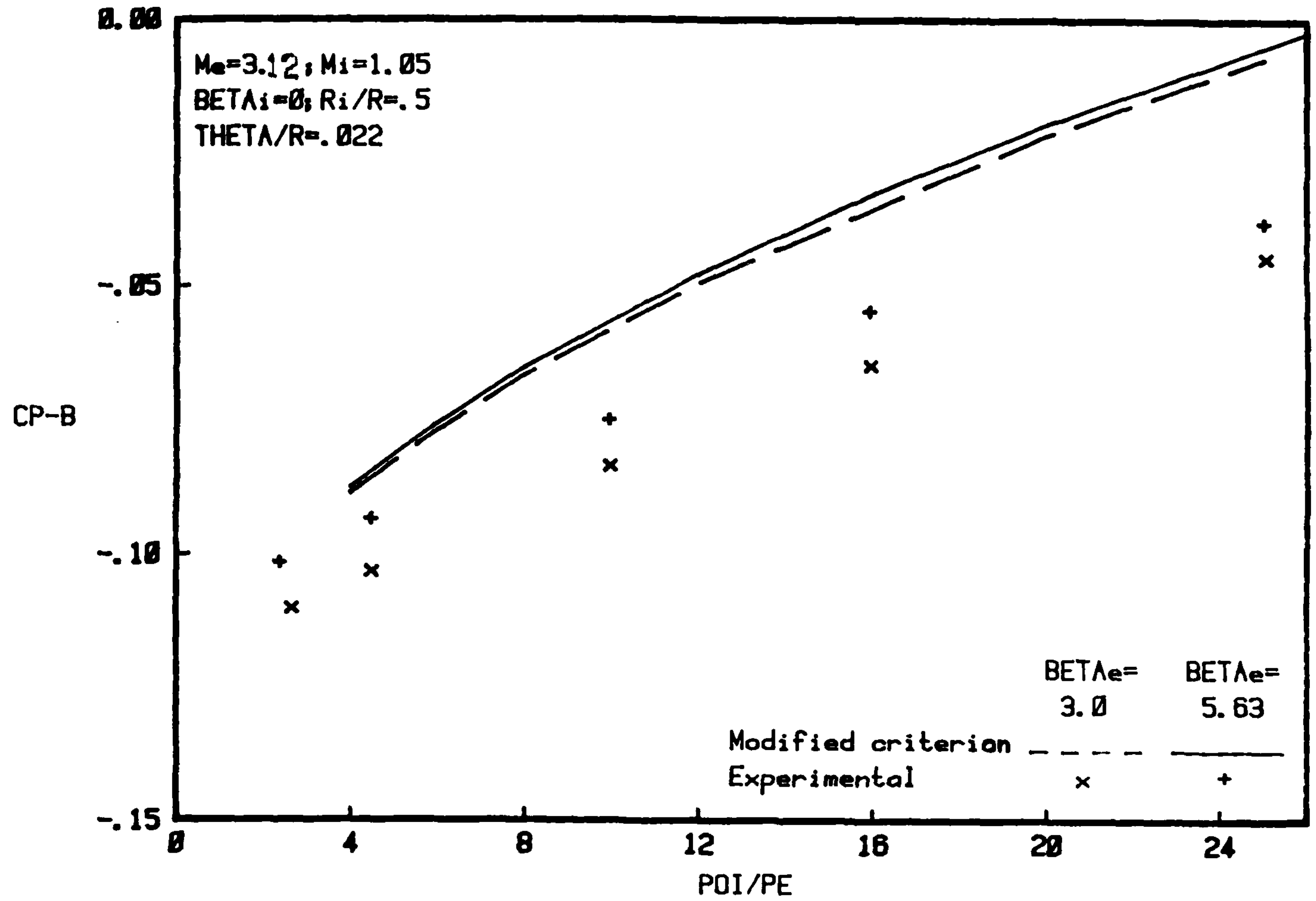

Figure 38. Comparison of calculated base pressures with experimental data from reference 23, (figure 24a), boattail angles = 3.00 and 5.63 degrees.

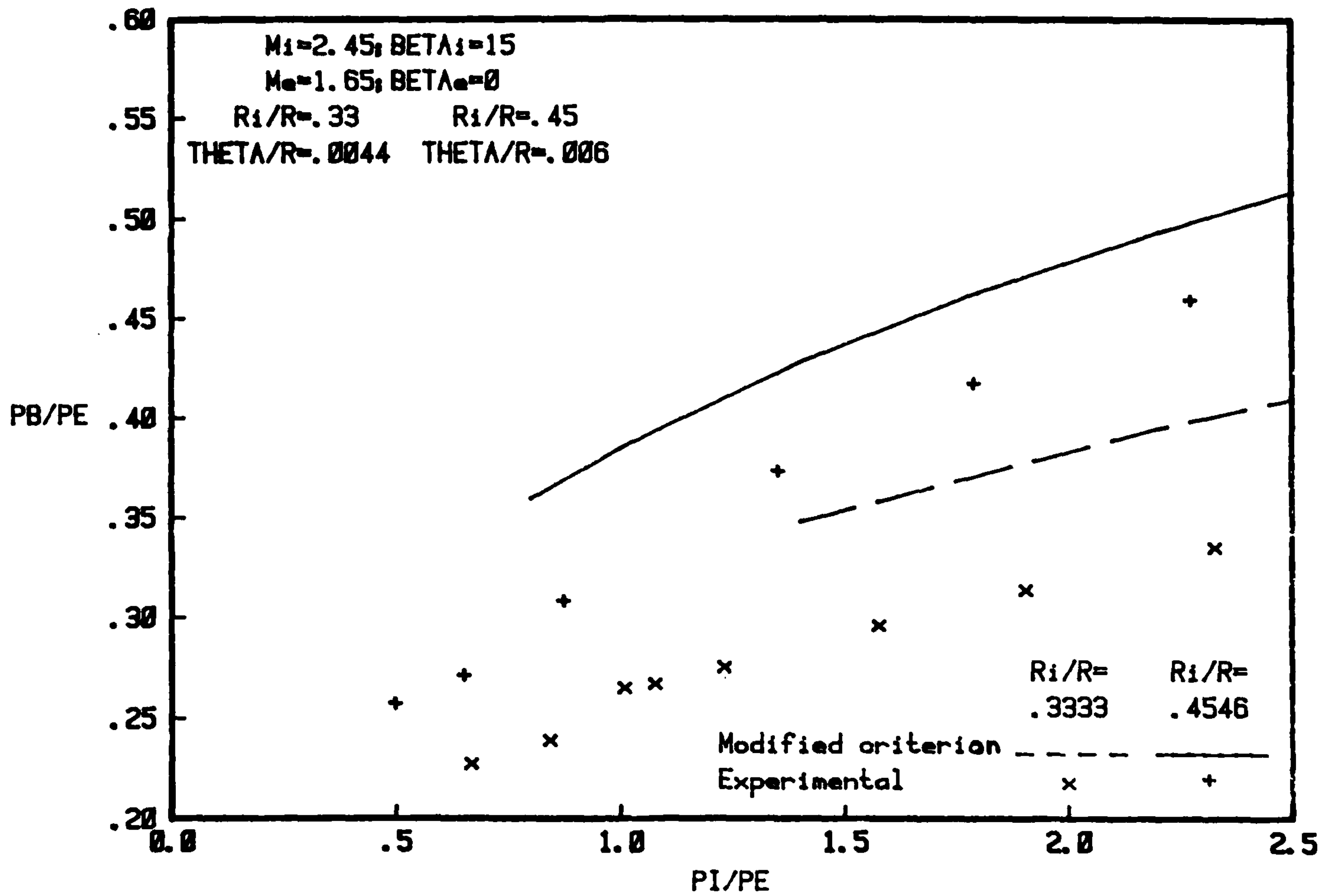

Figure 39. Comparison of calculated base pressures with experimental data from reference 24, (figure 9a), radius ratios = 0.3333 and 0.4546.

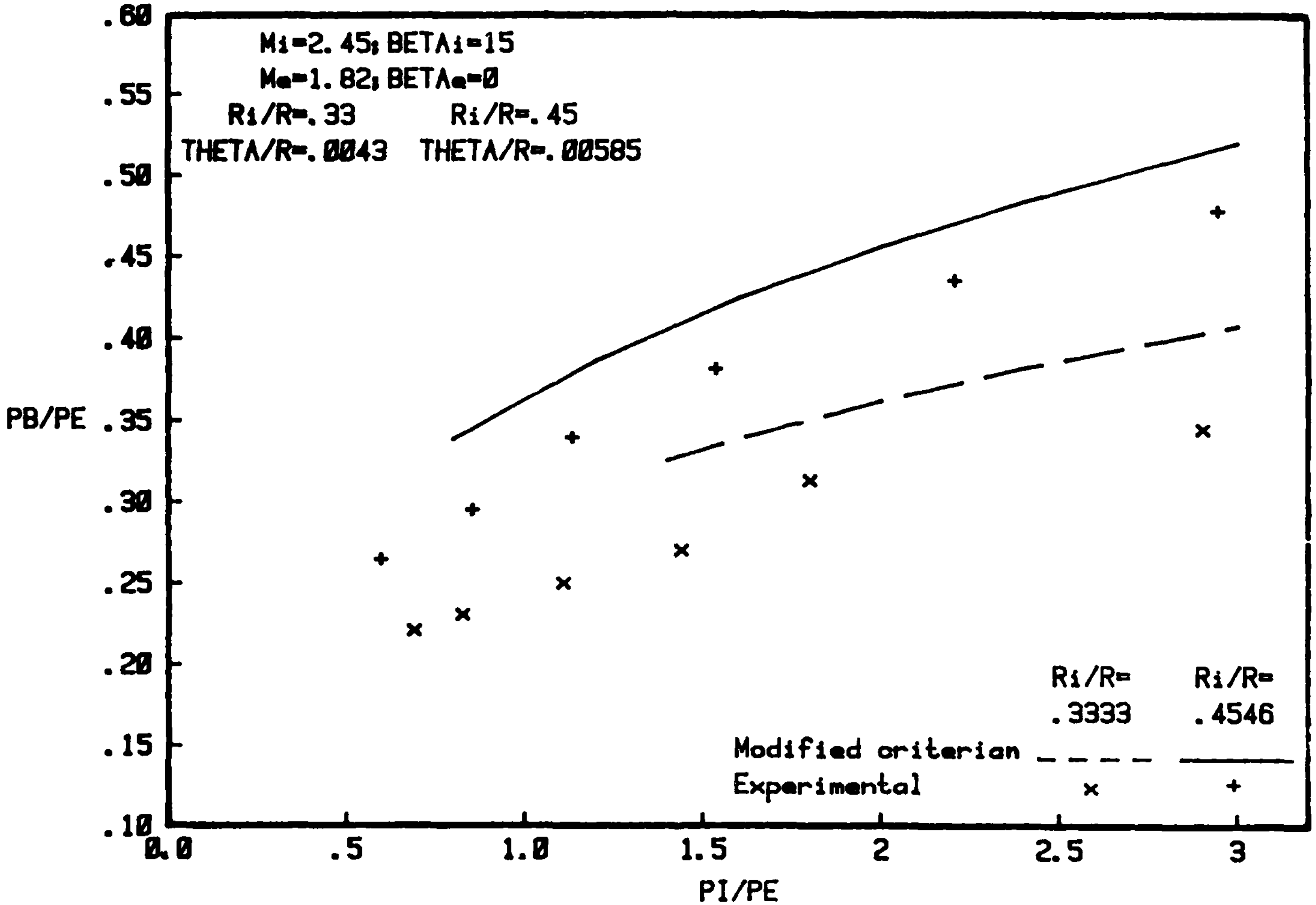

Figure 40. Comparison of calculated base pressures with experimental data from reference 24 (figure 9b), radius ratios = 0.3333 and 0.4546.

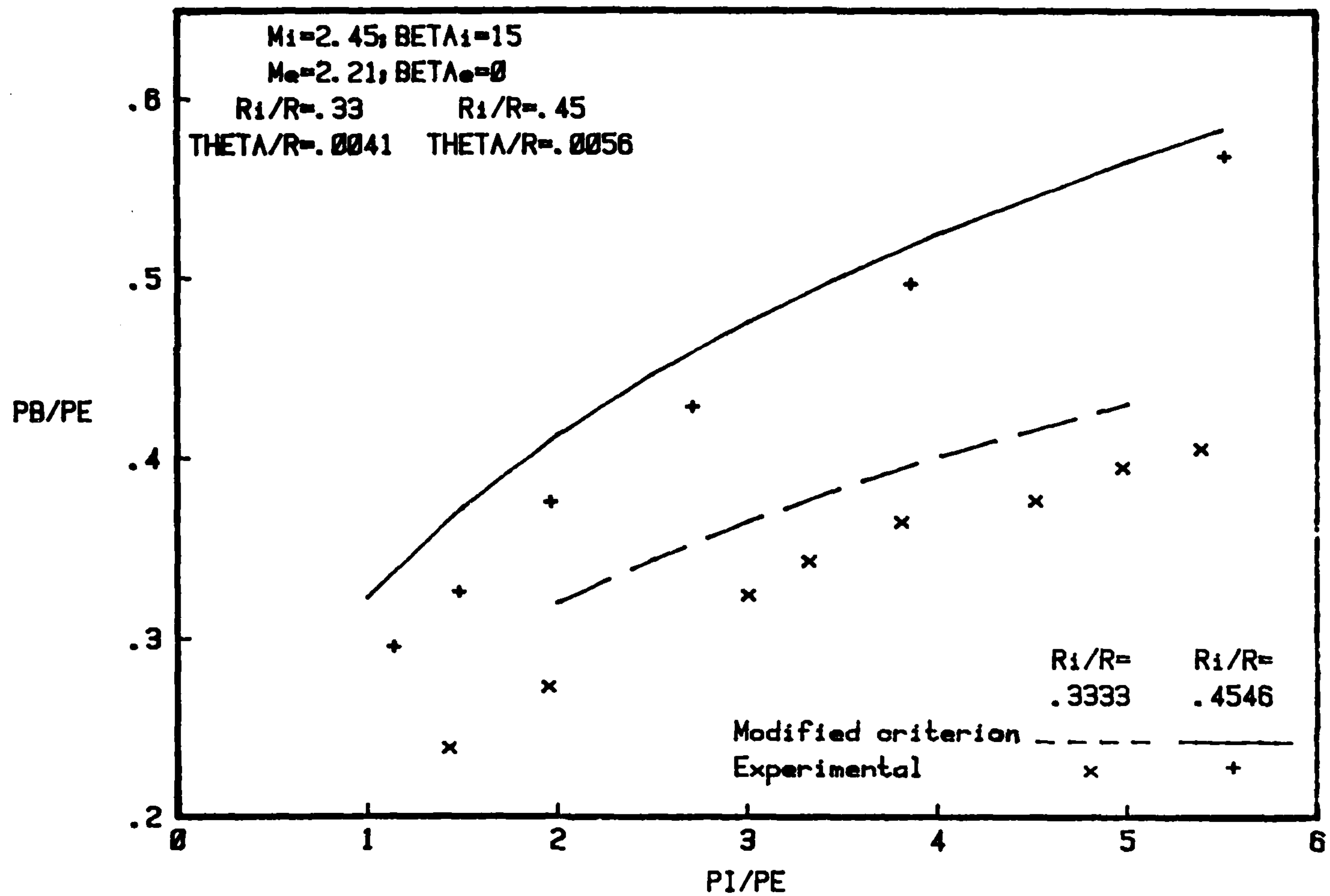

Figure 41. Comparison of calculated base pressures with experimental data from reference 24, (figure 9c), radius ratios = 0.3333 and 0.4546.

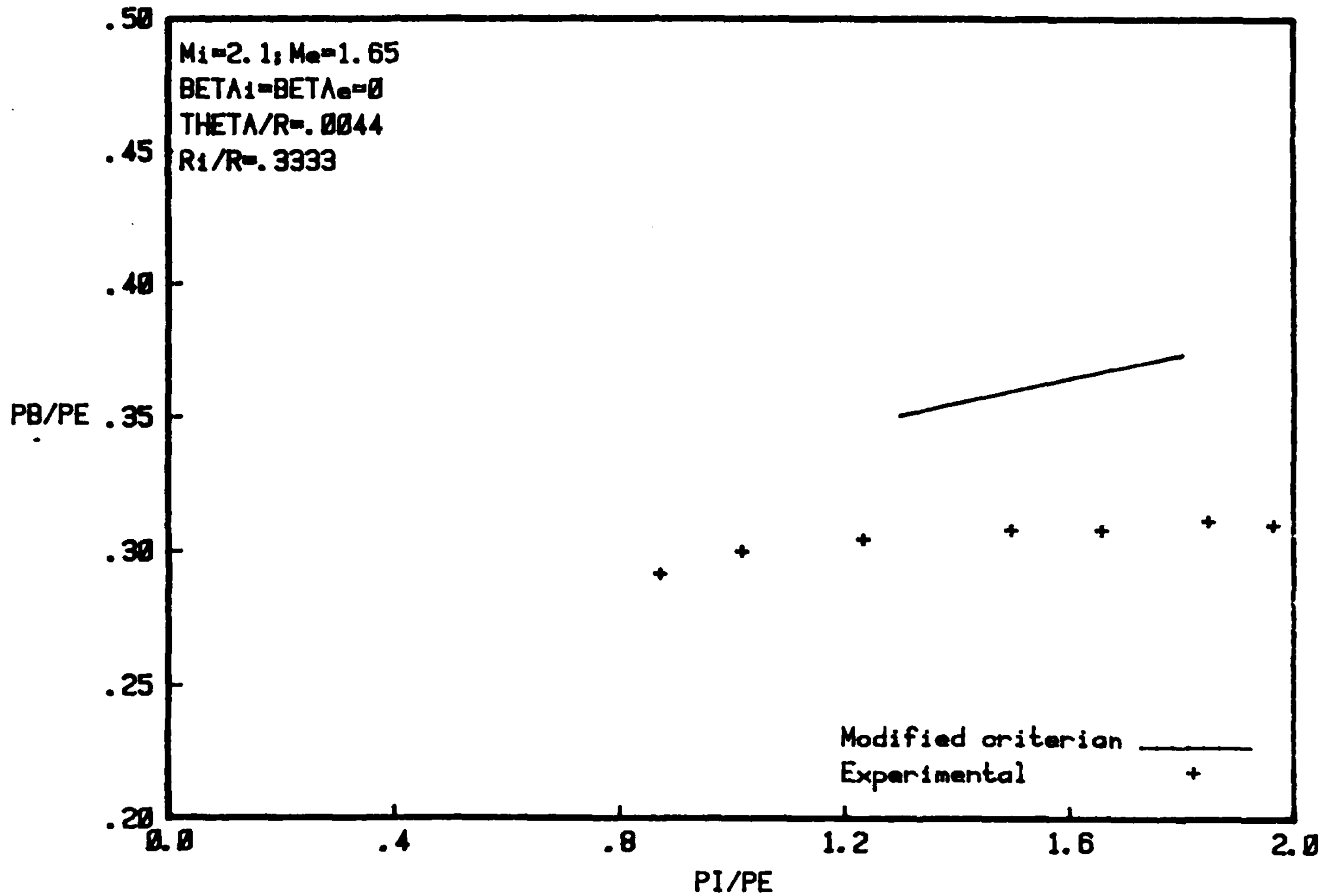

Figure 42. Comparison of calculated base pressures with experimental data from reference 24, (figure 9d), radius ratio = 0.3333.

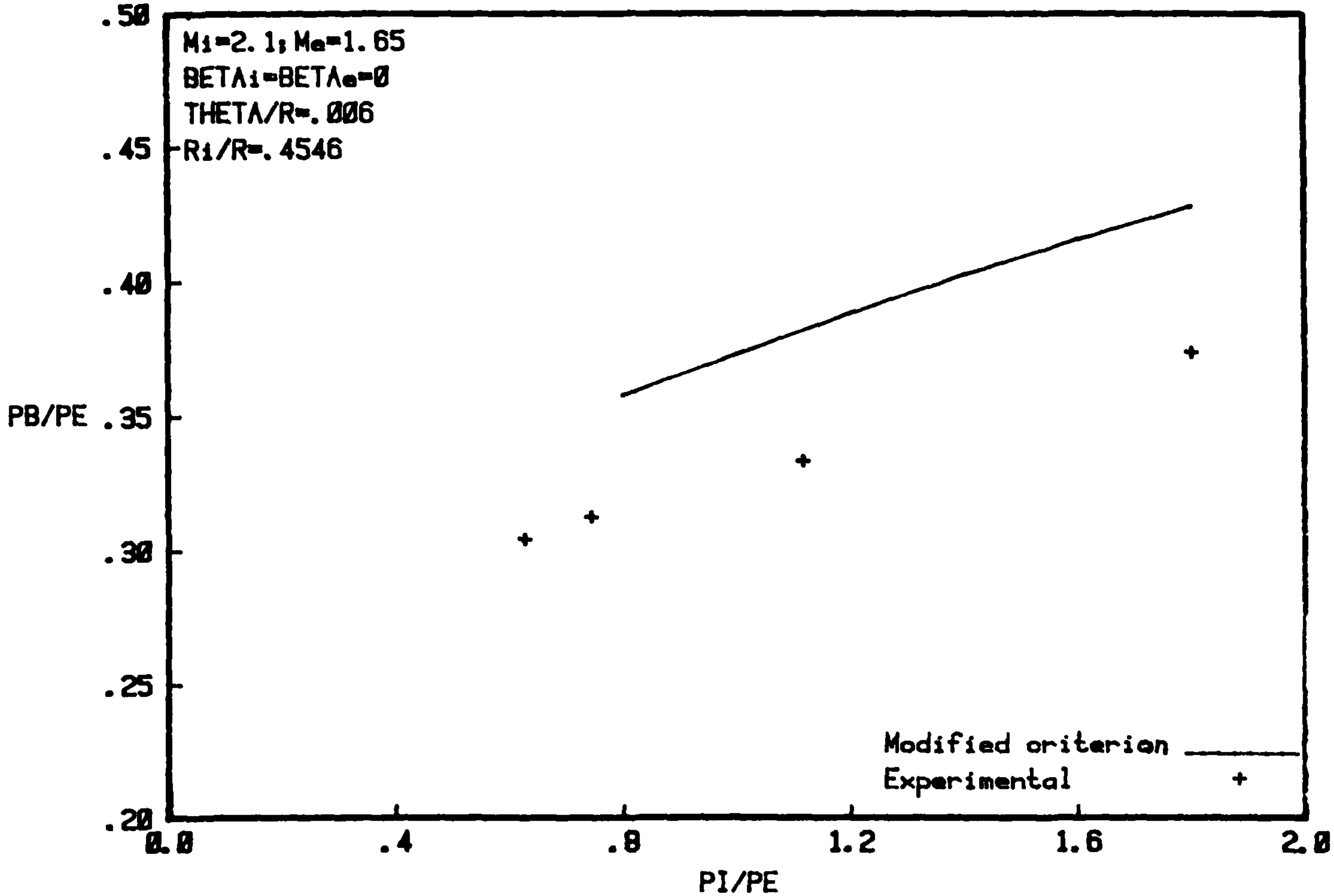

Figure 43. Comparison of calculated base pressures with experimental data from reference 24, (figure 9d), radius ratio = 0.4546.

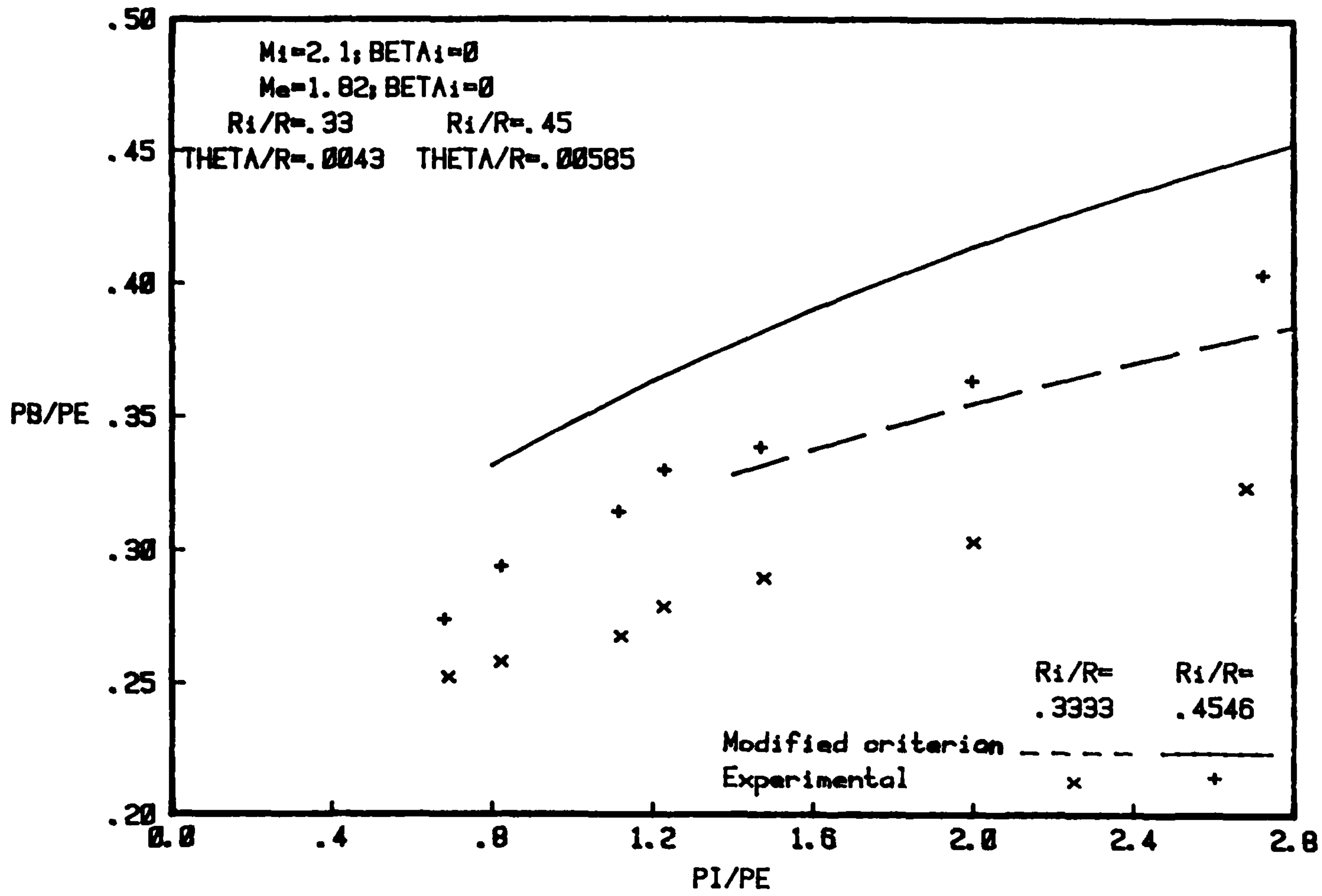

Figure 44. Comparison of calculated base pressures with experimental data from reference 24, (figure 9e), radius ratios = 0.3333 and 0.4546.

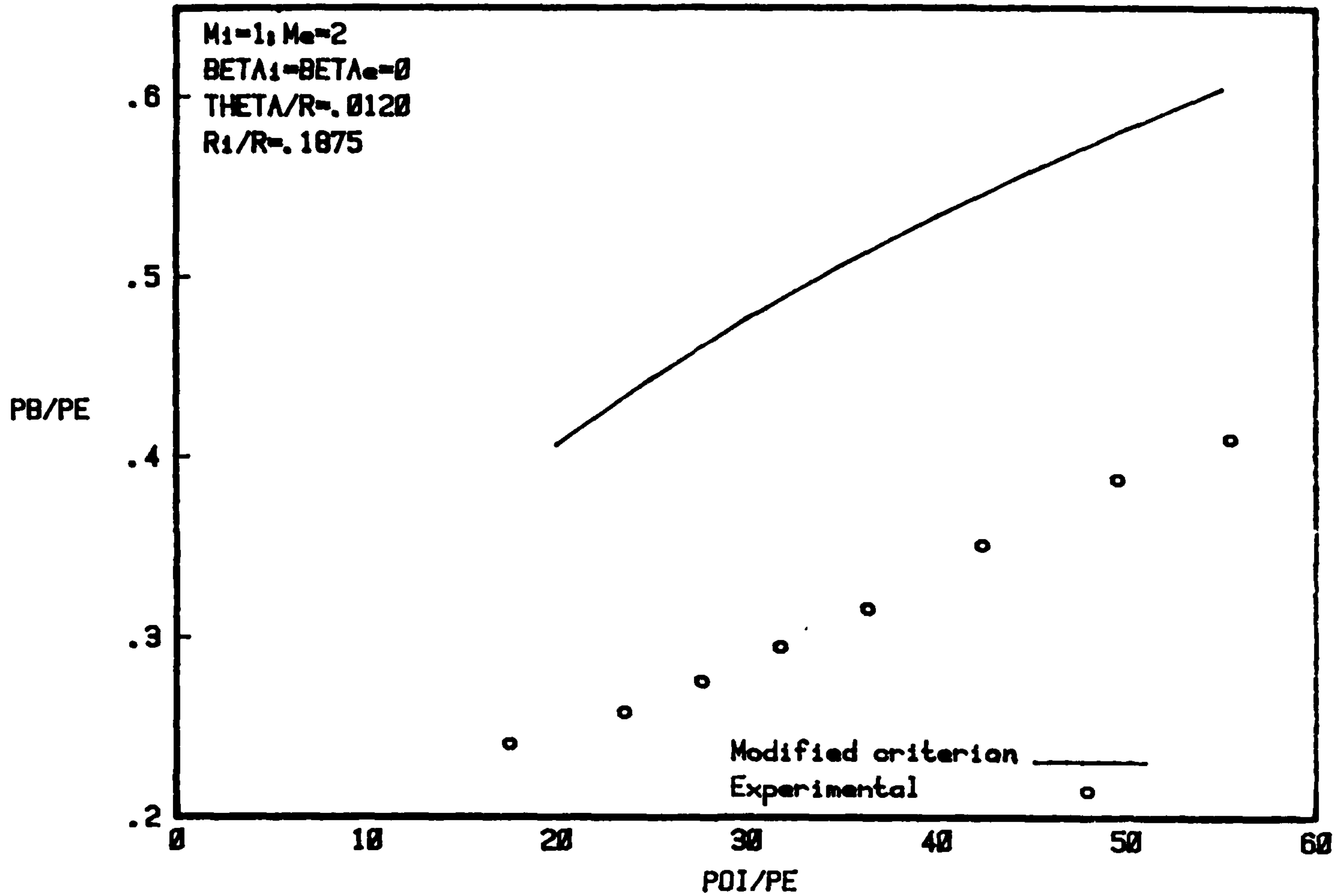

Figure 45. Comparison of calculated base pressures with experimental data from reference 25, (figure 4), sonic nozzle with radius ratio = 0.1875.

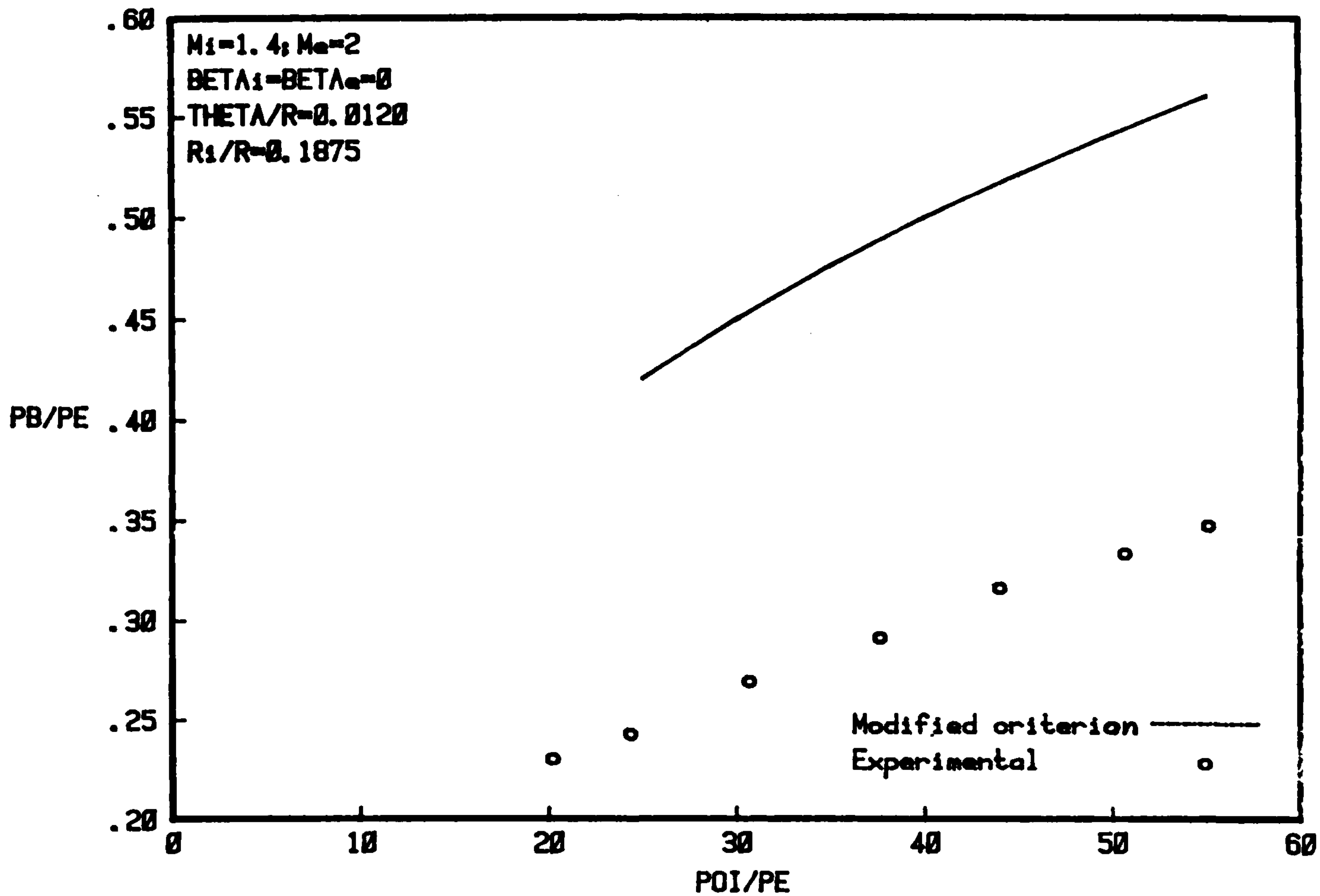

Figure 46. Comparison of calculated base pressures with experimental data from reference 25, (figure 4), mach 1.4 nozzle with radius ratio = 0.1875.

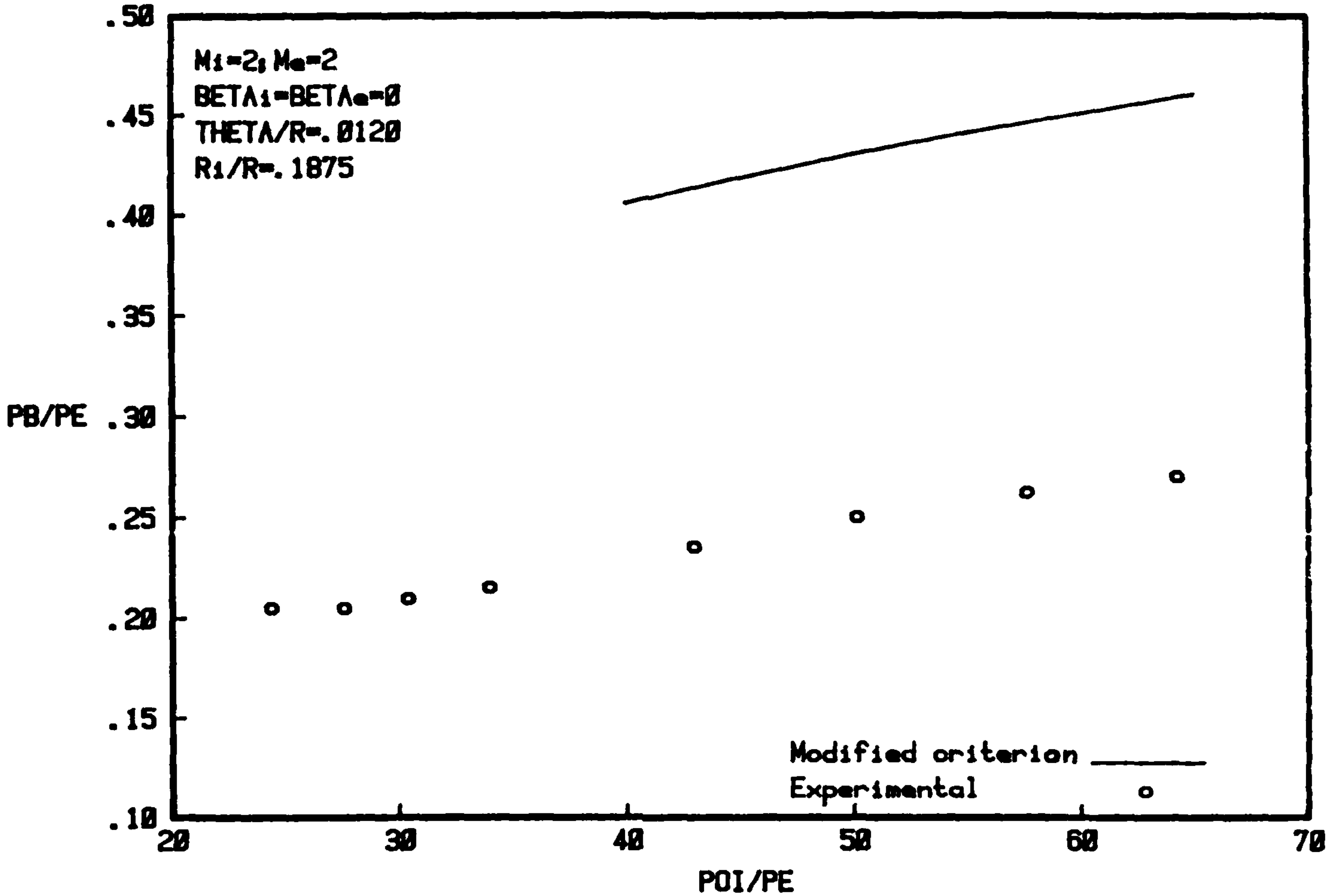

Figure 47. Comparison of calculated base pressures with experimental data from reference 25, (figure 4), mach 2.0 nozzle with radius ratio = 0.1875.

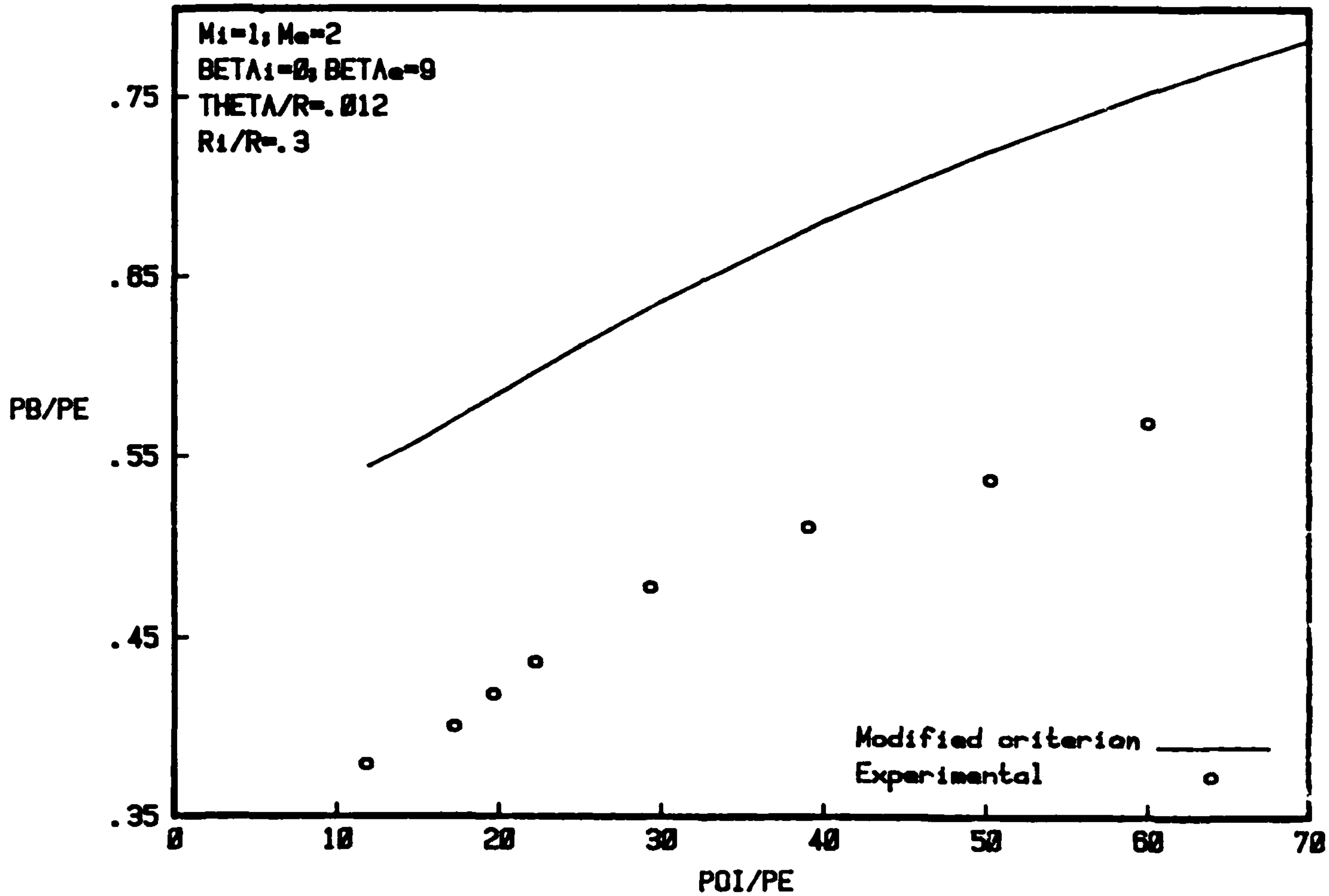

Figure 48. Comparison of calculated base pressures with experimental data from reference 25, (figure 5a), sonic nozzle with radius ratio = 0.3.

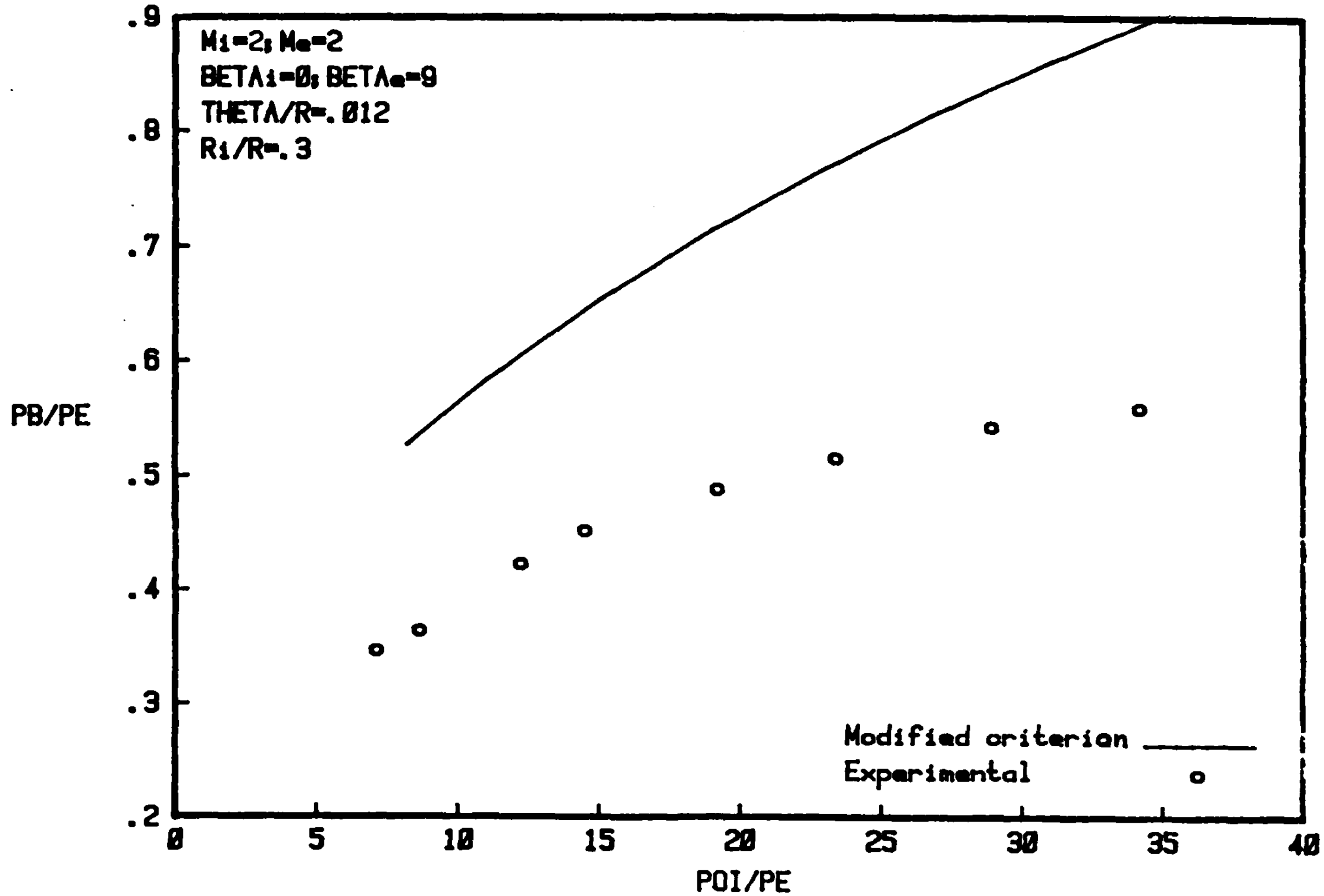

Figure 49. Comparison of calculated base pressures with experimental data from reference 25, (figure 5a), mach 2.0 nozzle with radius ratio = 0.3.

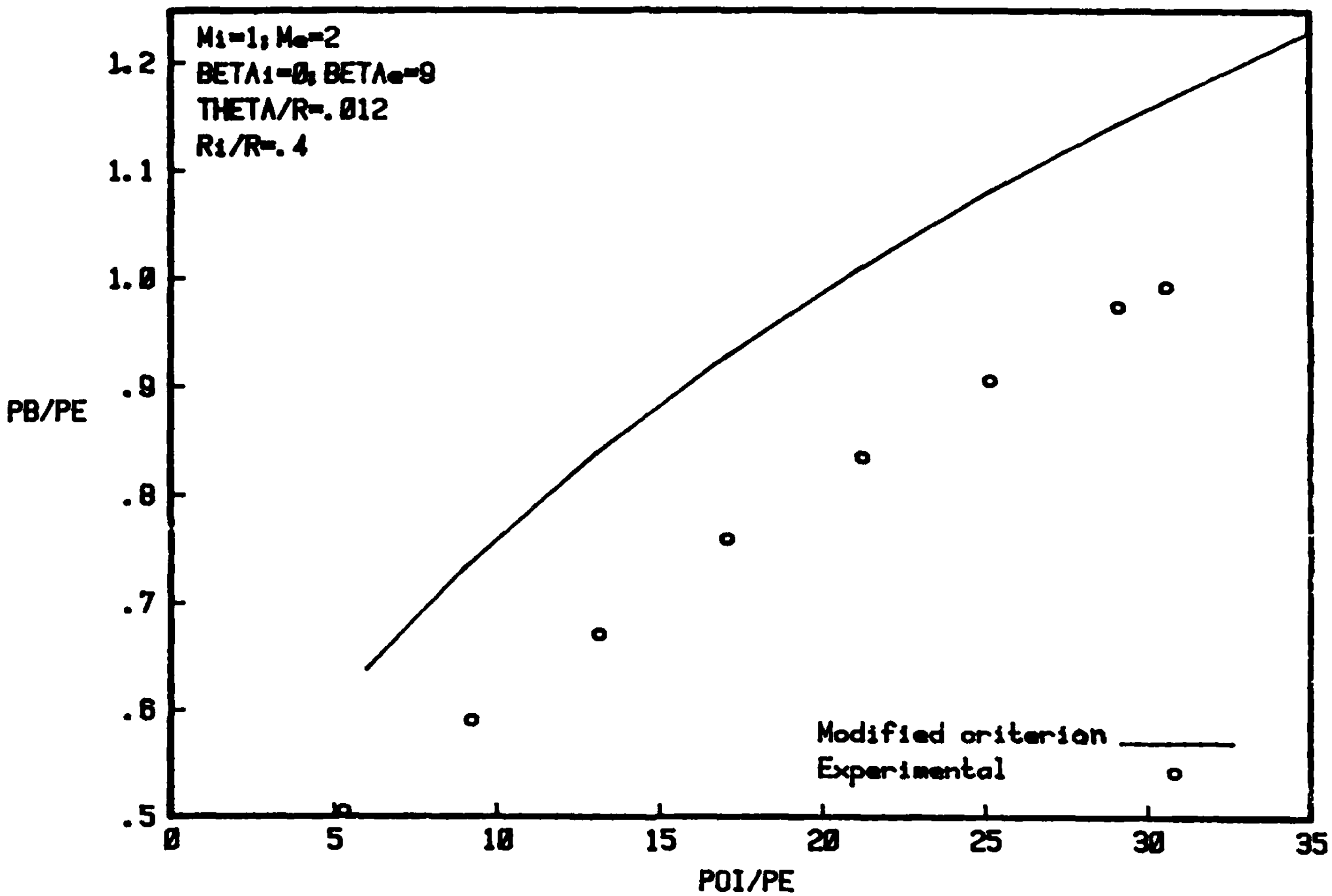

Figure 50. Comparison of calculated base pressures with experimental data from reference 25, (figure 5b), sonic nozzle with radius ratio = 0.4.

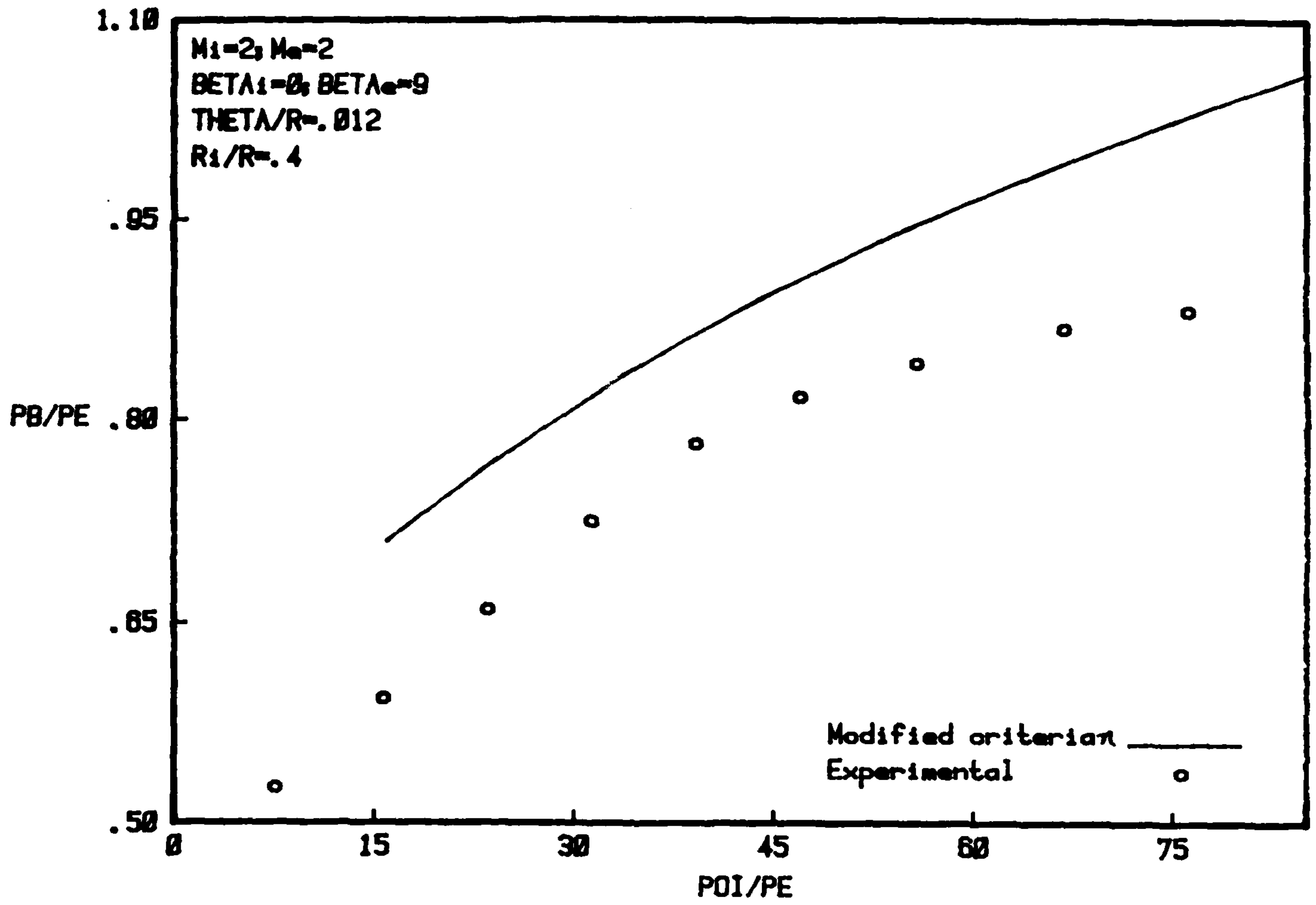

Figure 51. Comparison of calculated base pressures with experimental data from reference 25, (figure 5b), mach = 2.0 nozzle with radius ratio = 0.4.

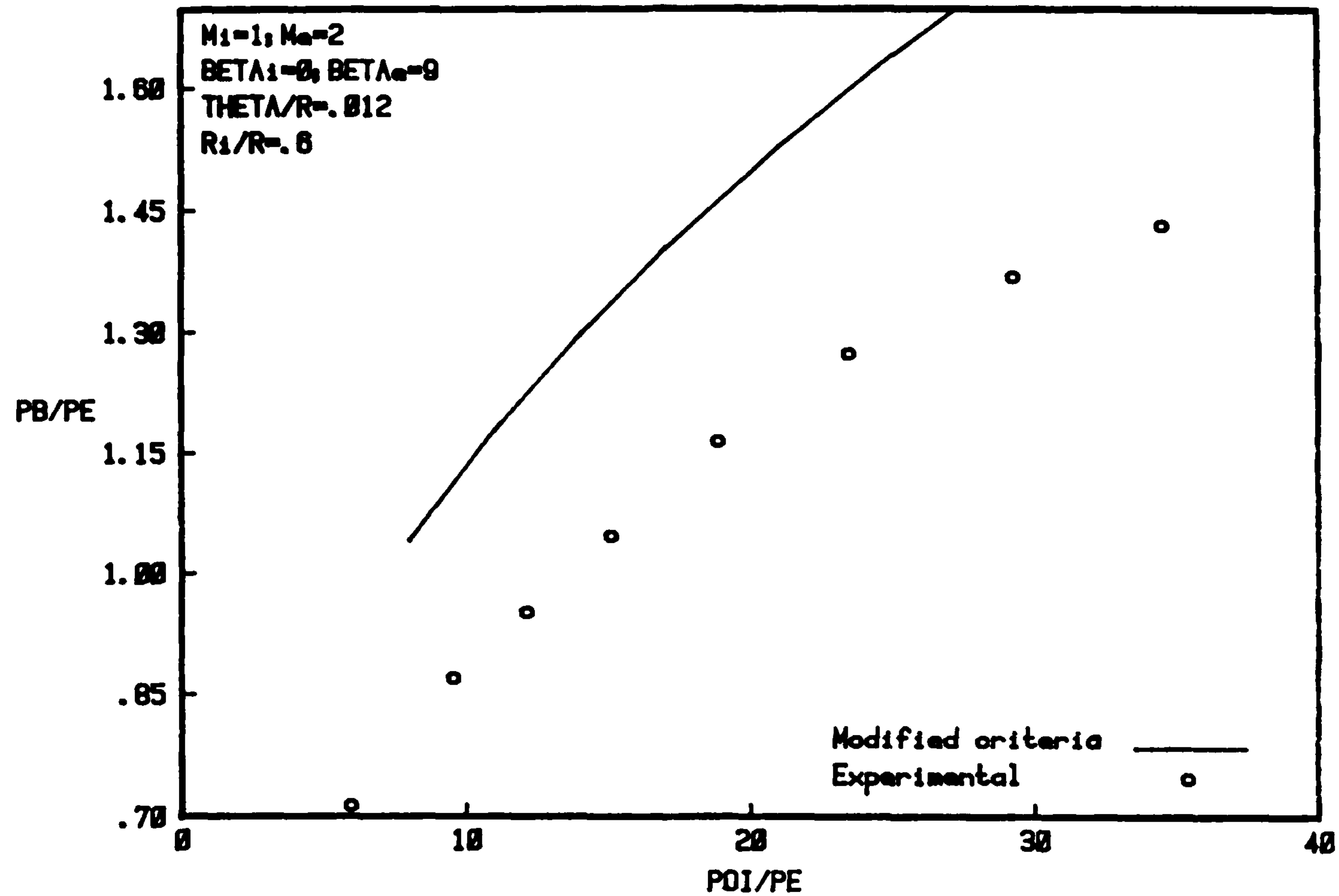

Figure 52. Comparison of calculated base pressures with experimental data from reference 25, (figure 5c), sonic nozzle with radius ratio = 0.6.

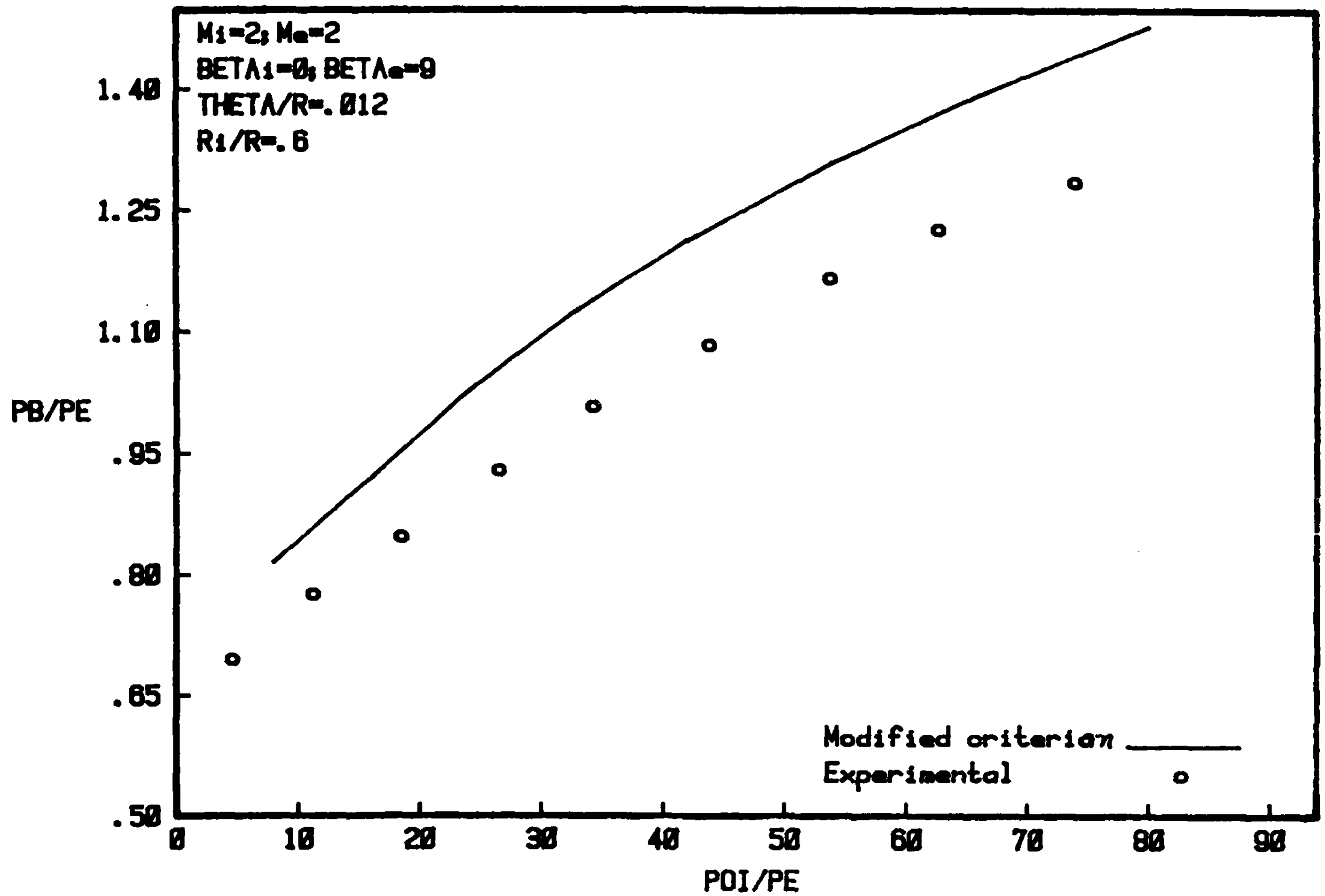

Figure 53. Comparison of calculated base pressures with experimental data from reference 25, (figure 5c), mach = 2.0 nozzle with radius ratio = 0.6.

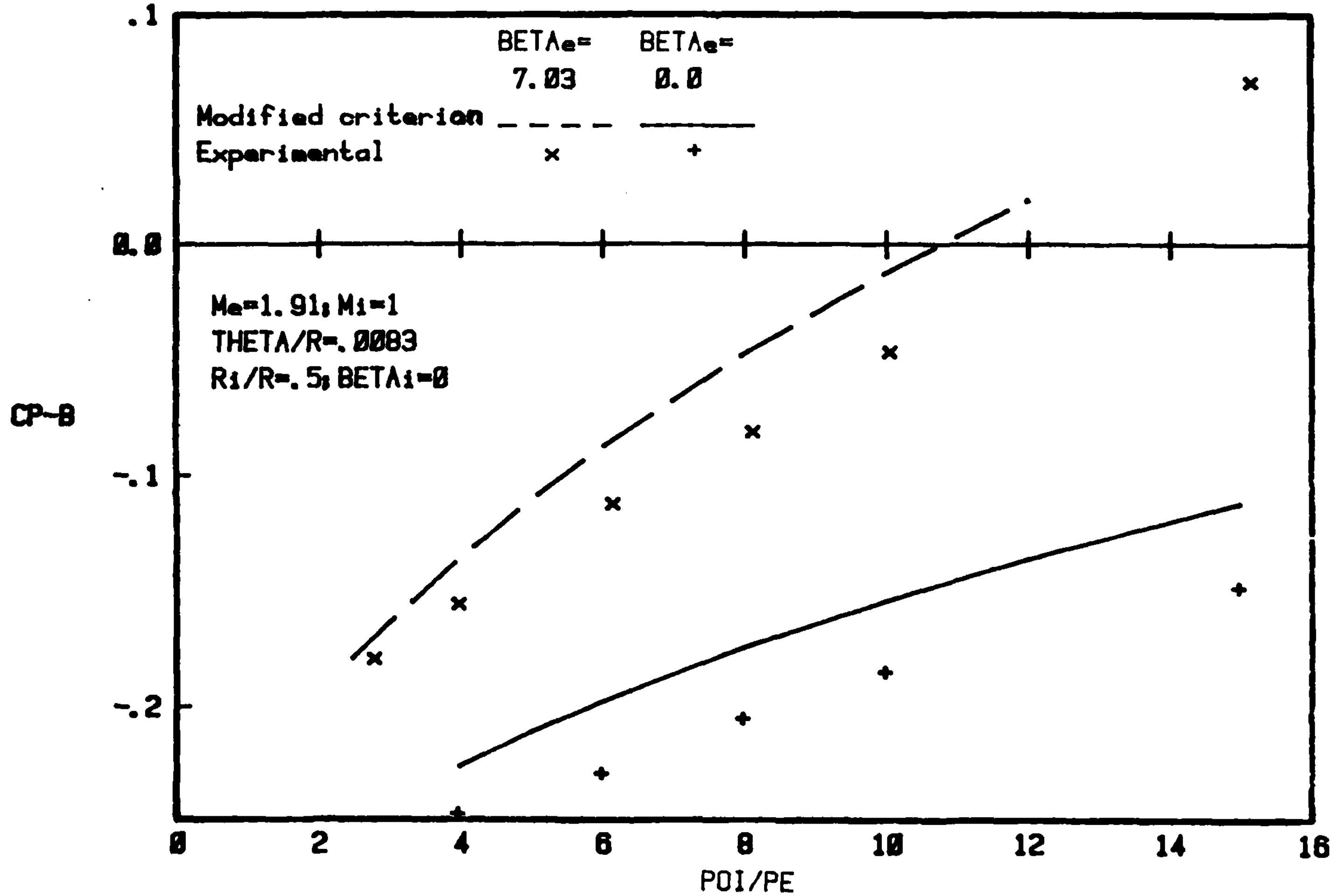

Figure 54. <u>Comparison of calculated base pressures with experimental data from reference 26, cylindrical afterbody and 7° boattail</u>.

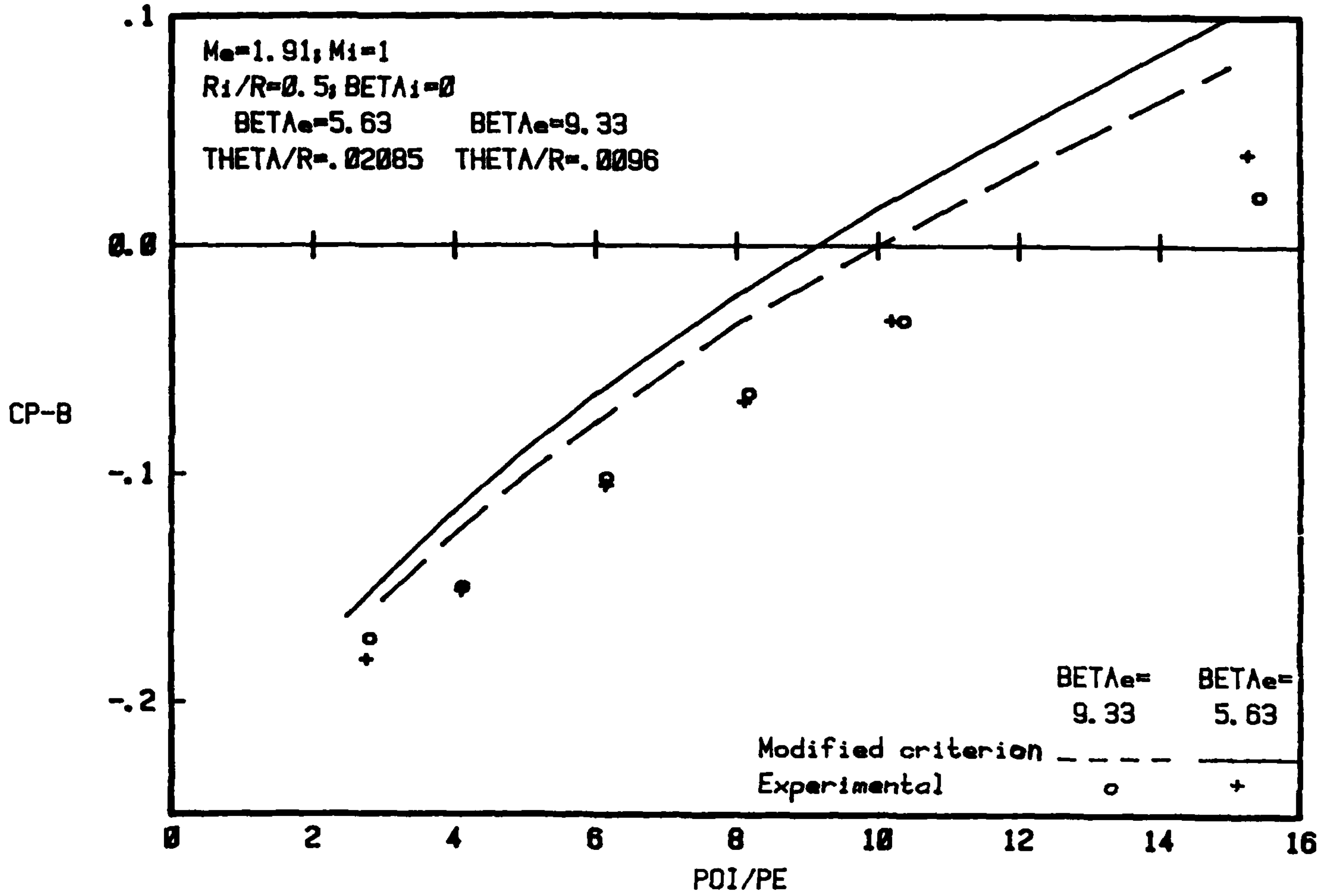

Figure 55. Comparison of calculated base pressures with experimental data from reference 26, 5° and 9° boattails.

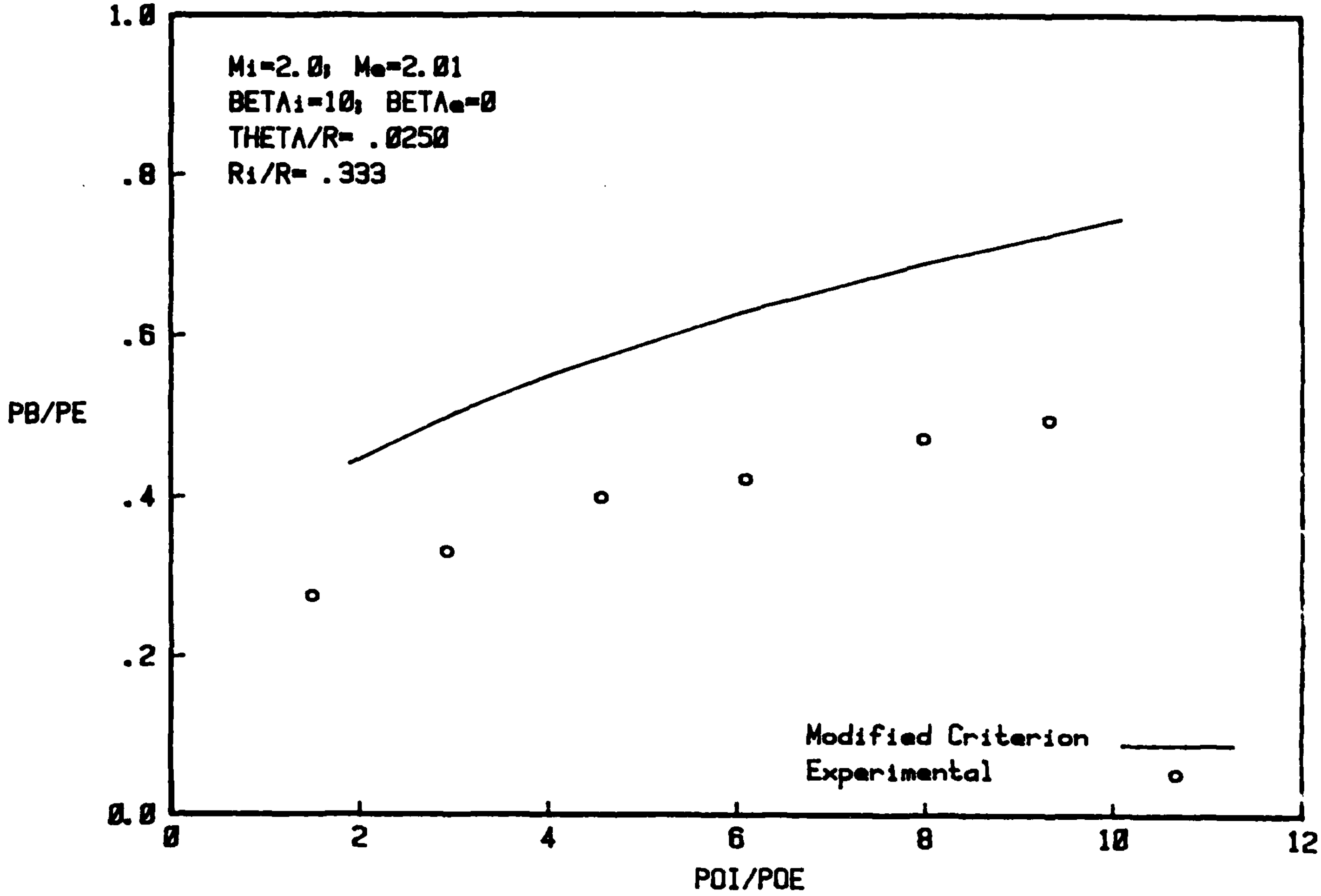

Figure 56. Comparison of calculated base pressures with experimental data from reference 27, (figure 11).

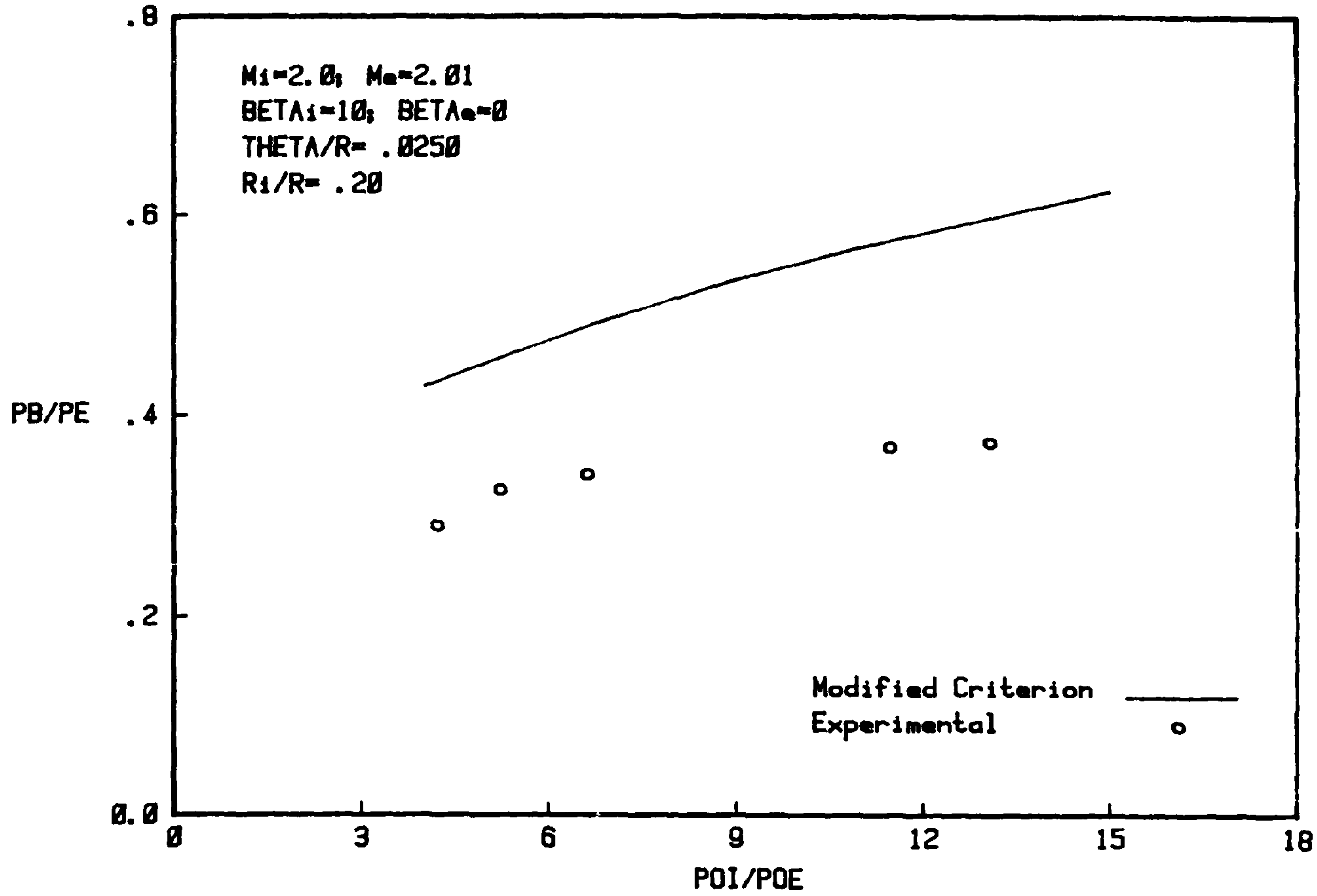

Figure 57. Comparison of calculated base pressures with experimental data from reference 27, (figure 12).

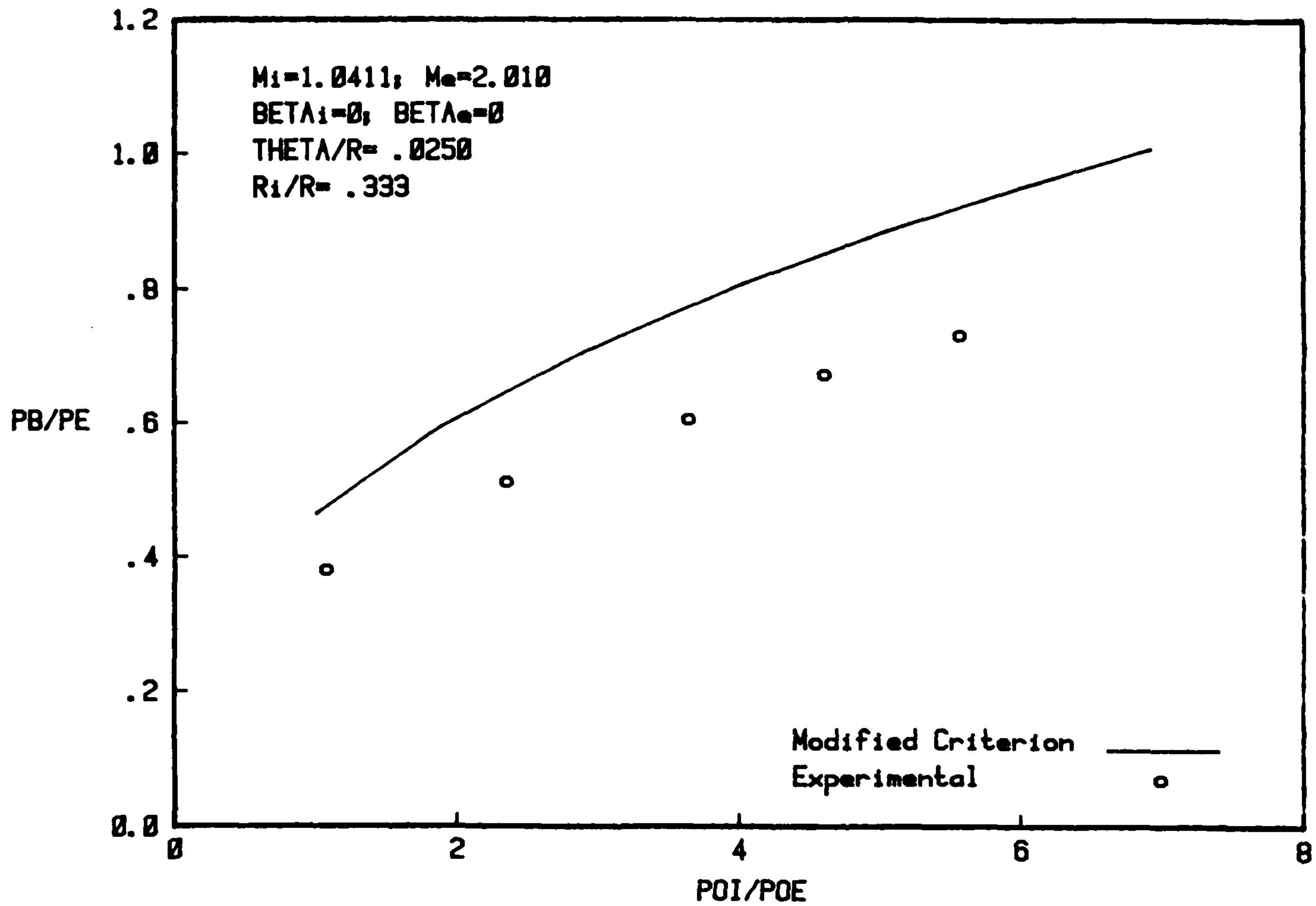

Figure 58. Comparison of calculated base pressures with experimental data from reference 27, (figure 14).

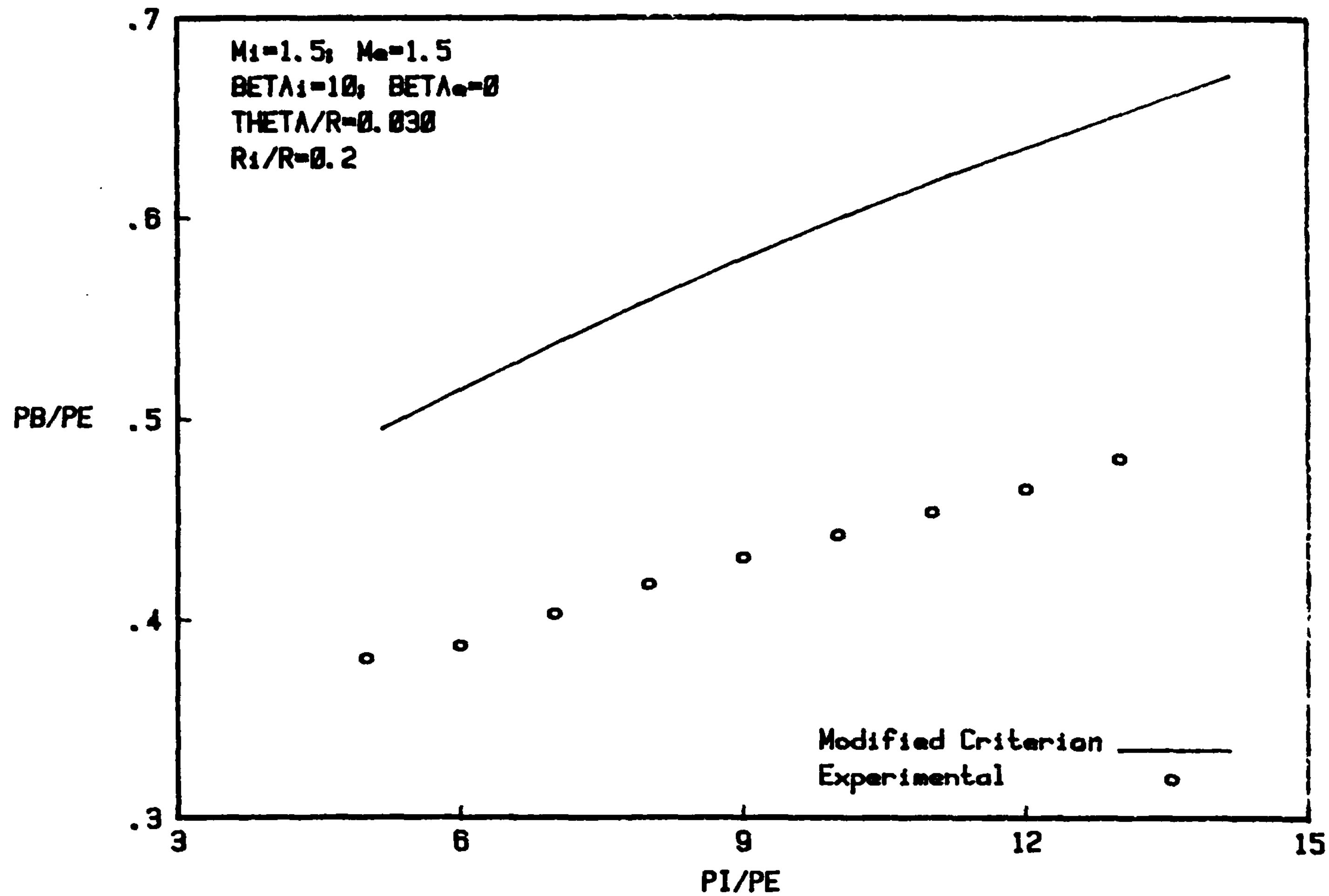

Figure 59. Comparison of calculated base pressures with experimental data from reference 27, (figure 14).

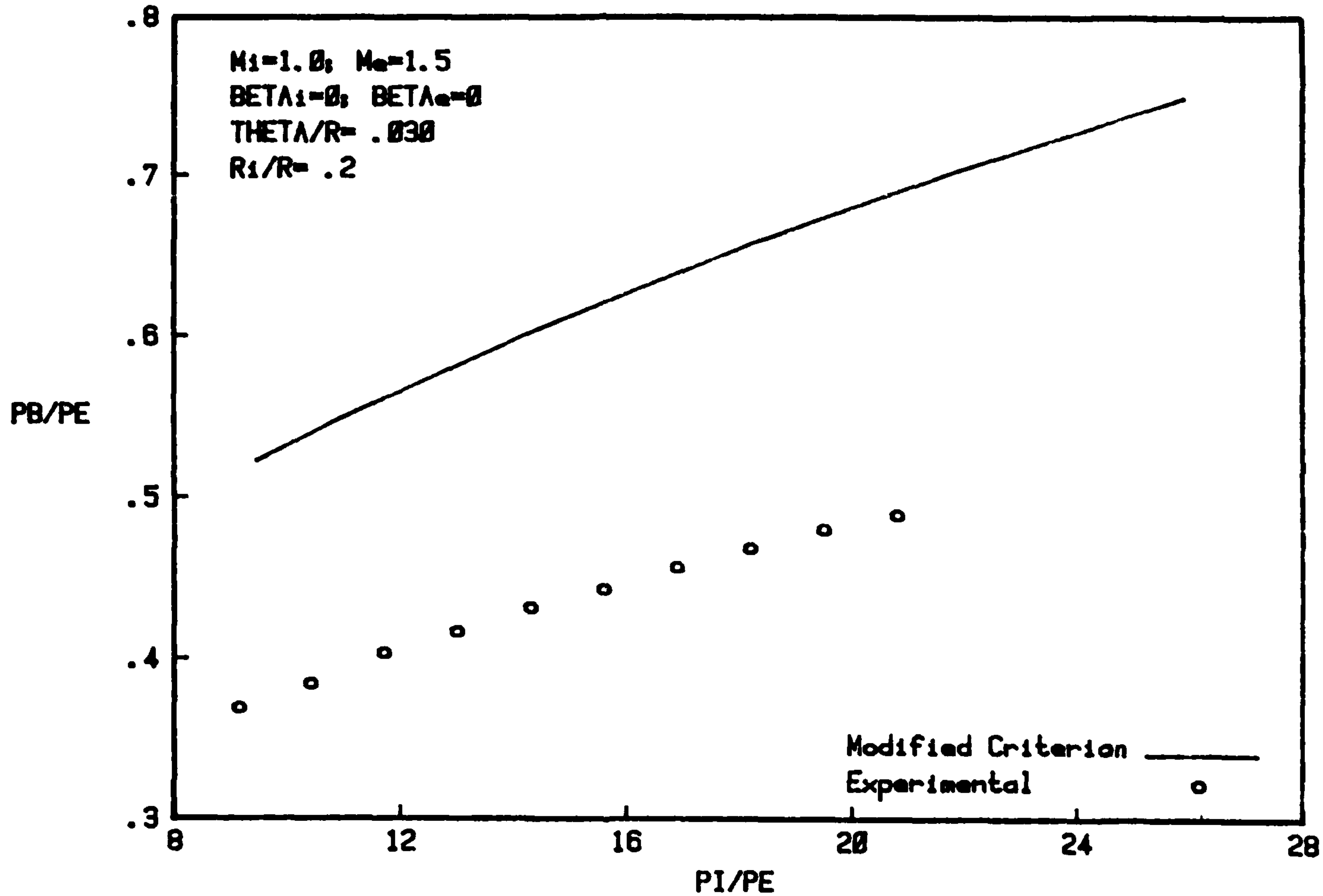

Figure 60. Comparison of calculated base pressures with experimental data from reference 27, (figure 28).

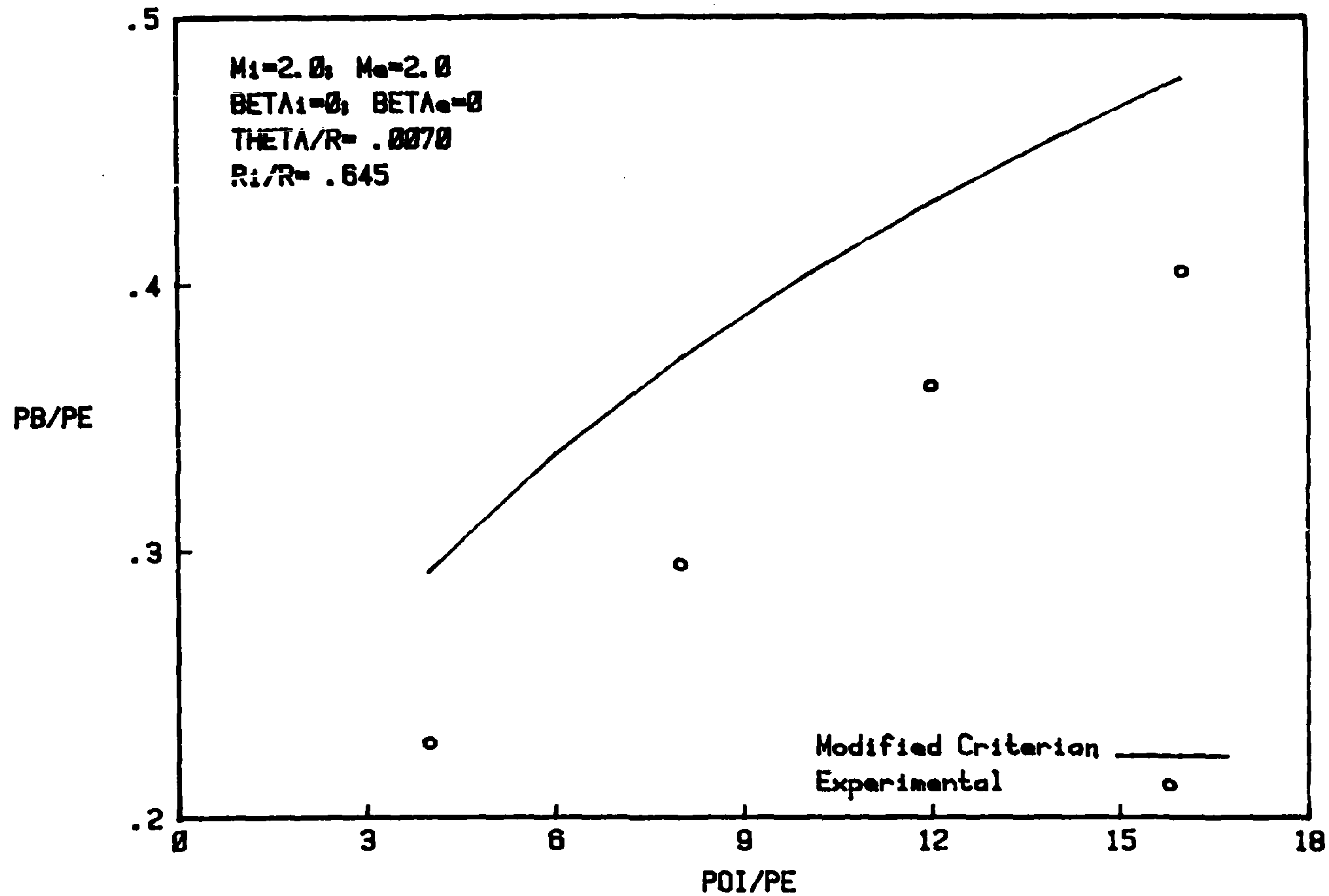

Figure 61. Comparison of calculated base pressures with experimental data from reference 28, (figure 11), isoenergetic data.

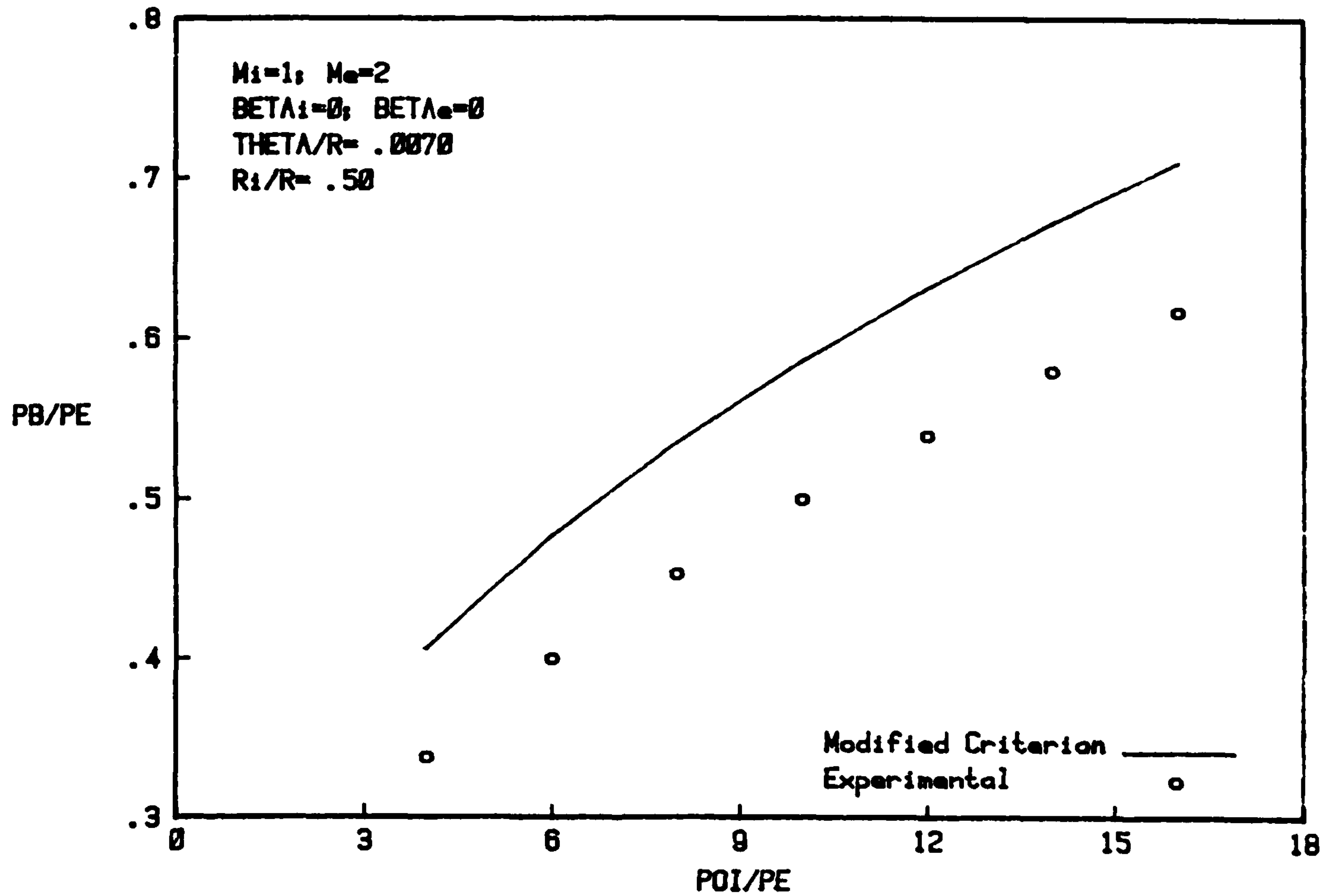

Figure 62. Comparison of calculated base pressures with experimental data from reference 28, (figure 13), isoenergetic data.

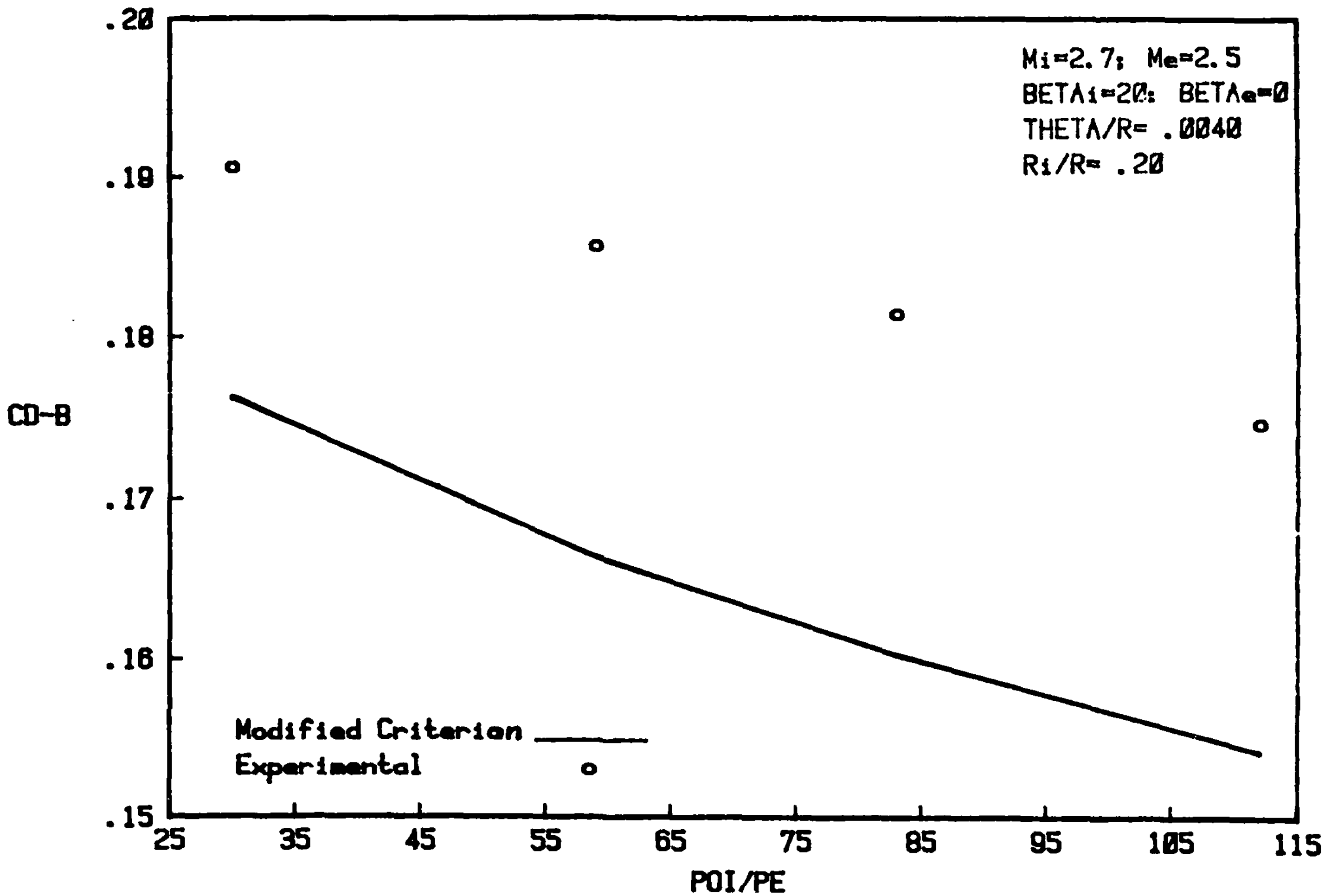

Figure 63. Comparison of calculated base drag coefficients with experimental data from reference 29, (figure 4), no bleed, $M_\infty = 2.5$.

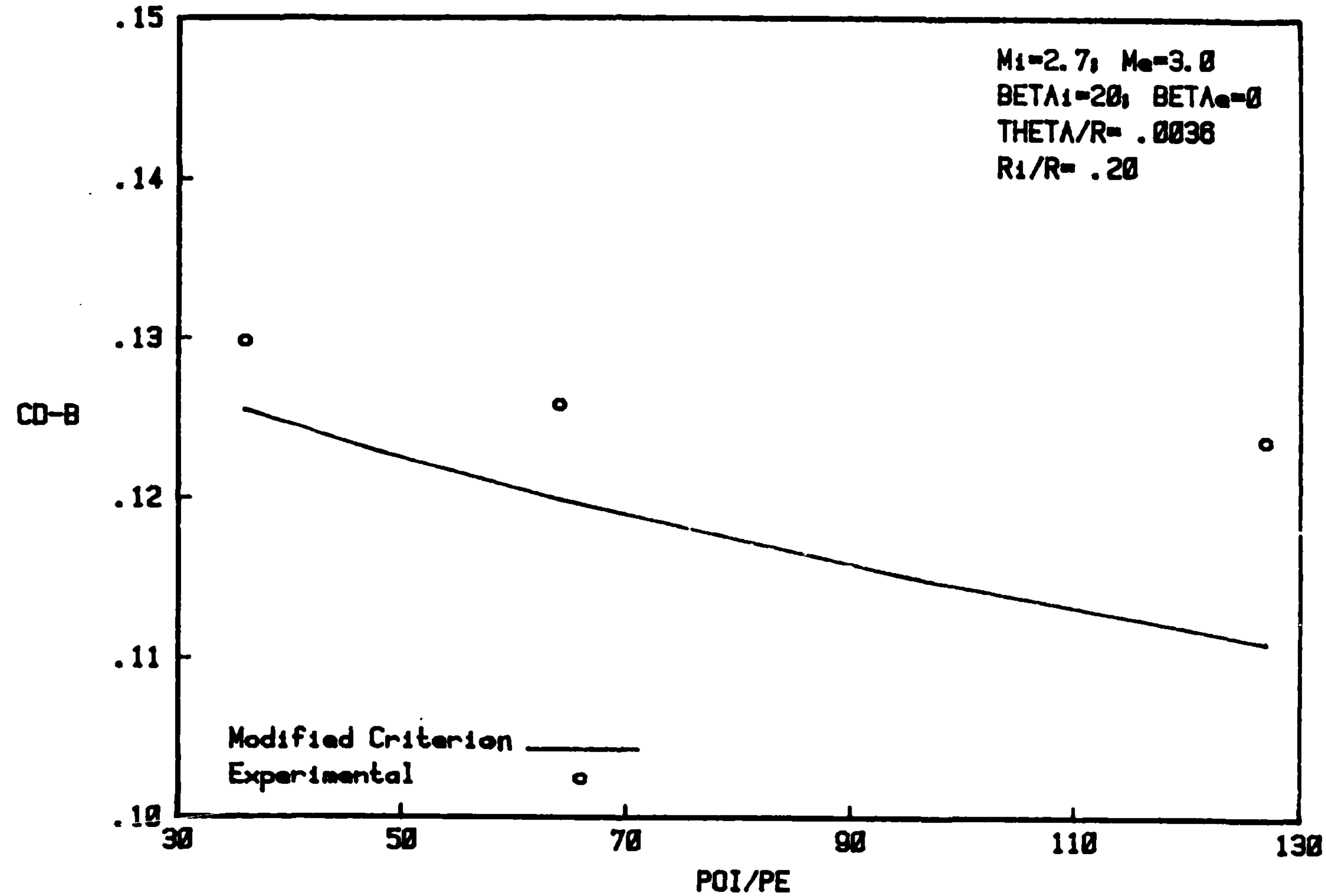

Figure 64. Comparison of calculated base drag coefficients with experimental data from reference 29, (figure 5), no bleed, $M_\infty = 3.0$.

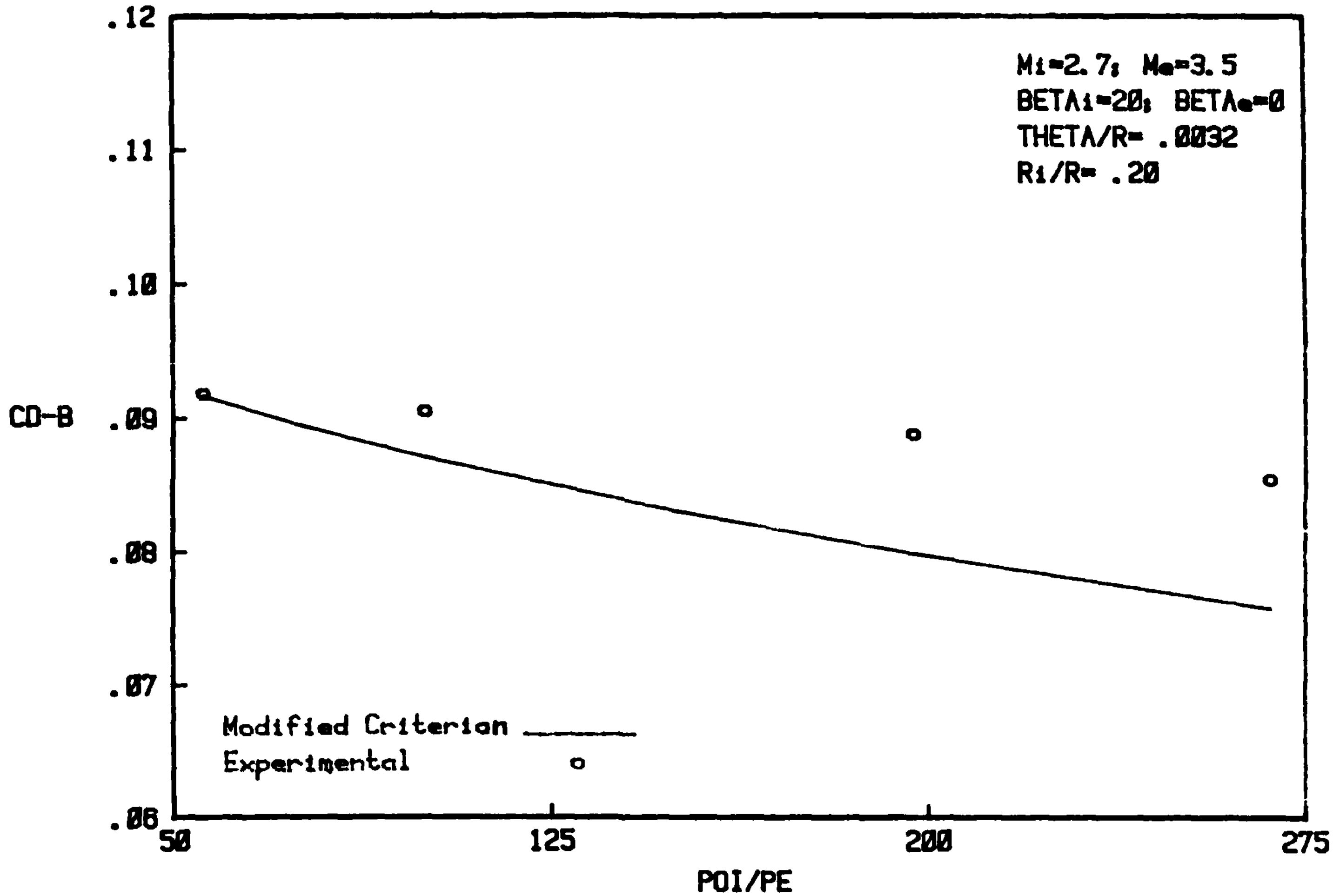

Figure 65. Comparison of calculated base drag coefficients with experimental data from reference 29, (figure 6), no bleed, $M_\infty = 3.5$.

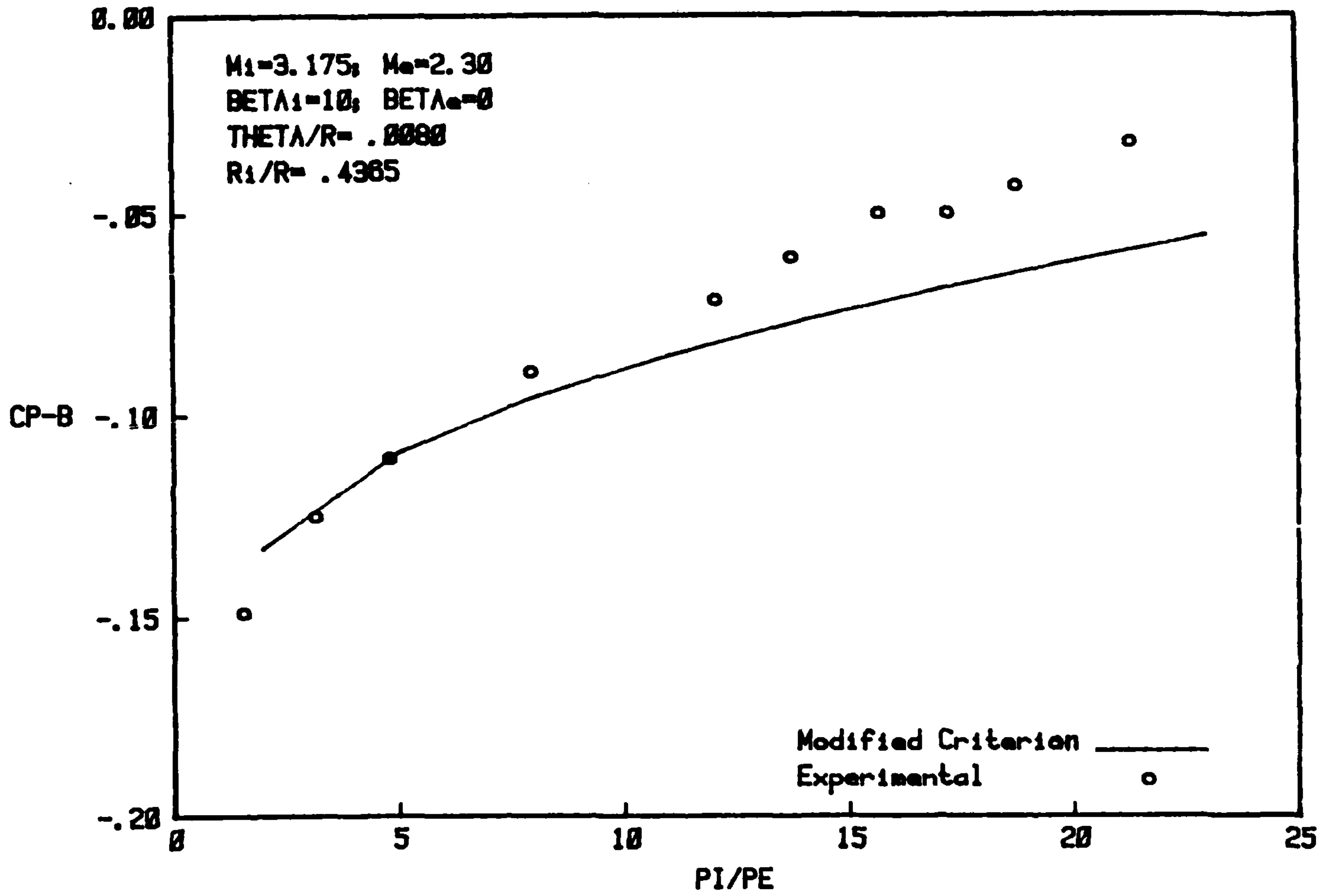

Figure 66. Comparison of calculated base pressures with experimental data from reference 30, (figure 10a), single jet, $M_\infty = 2.30$.

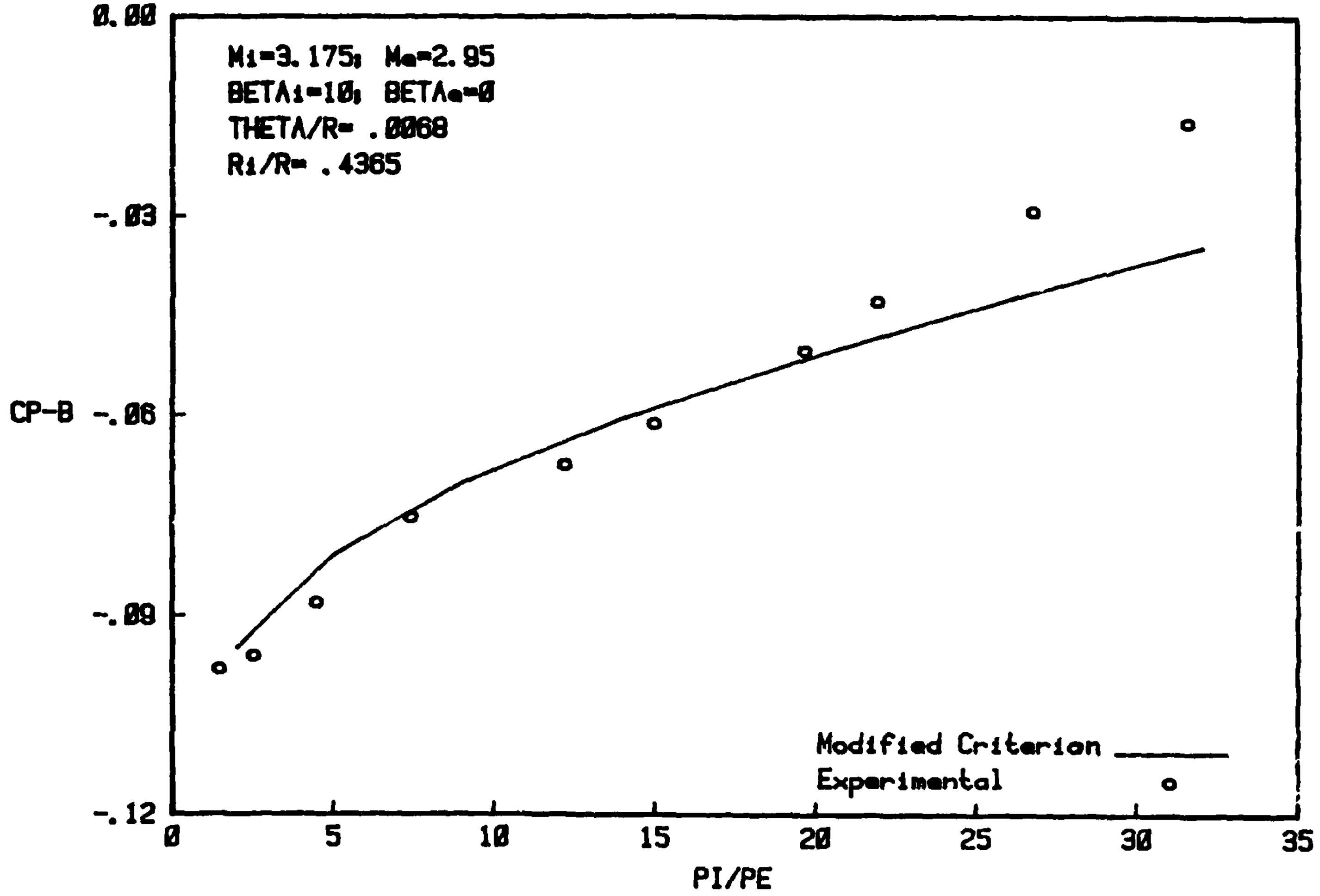

Figure 67. Comparison of calculated base pressures with experimental data from reference 30, (figure 10b), single jet, $M_\infty = 2.95$.

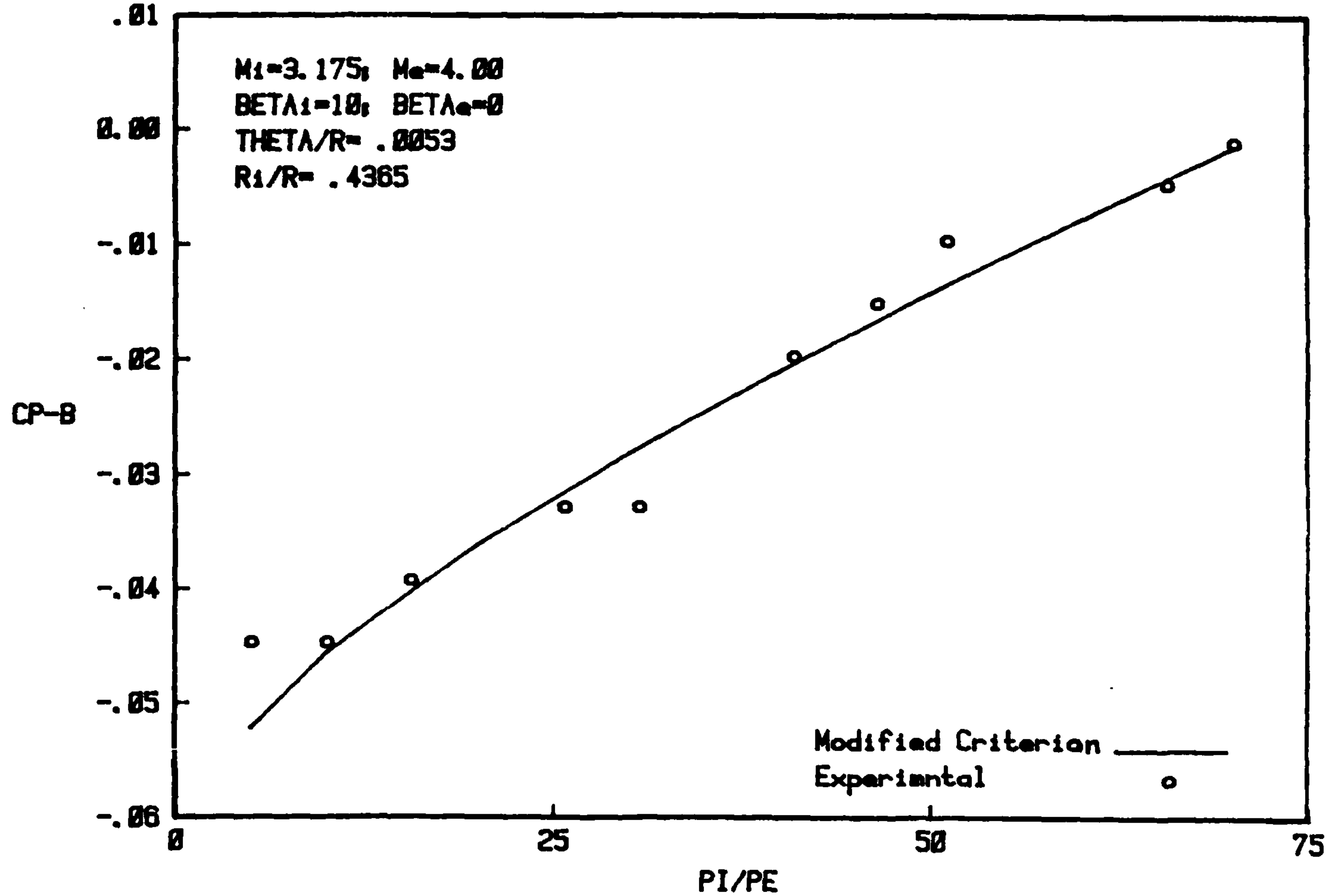

Figure 68. Comparison of calculated base pressures with experimental data from reference 30, (figure 10c), single jet, $M_\infty = 4.00$.

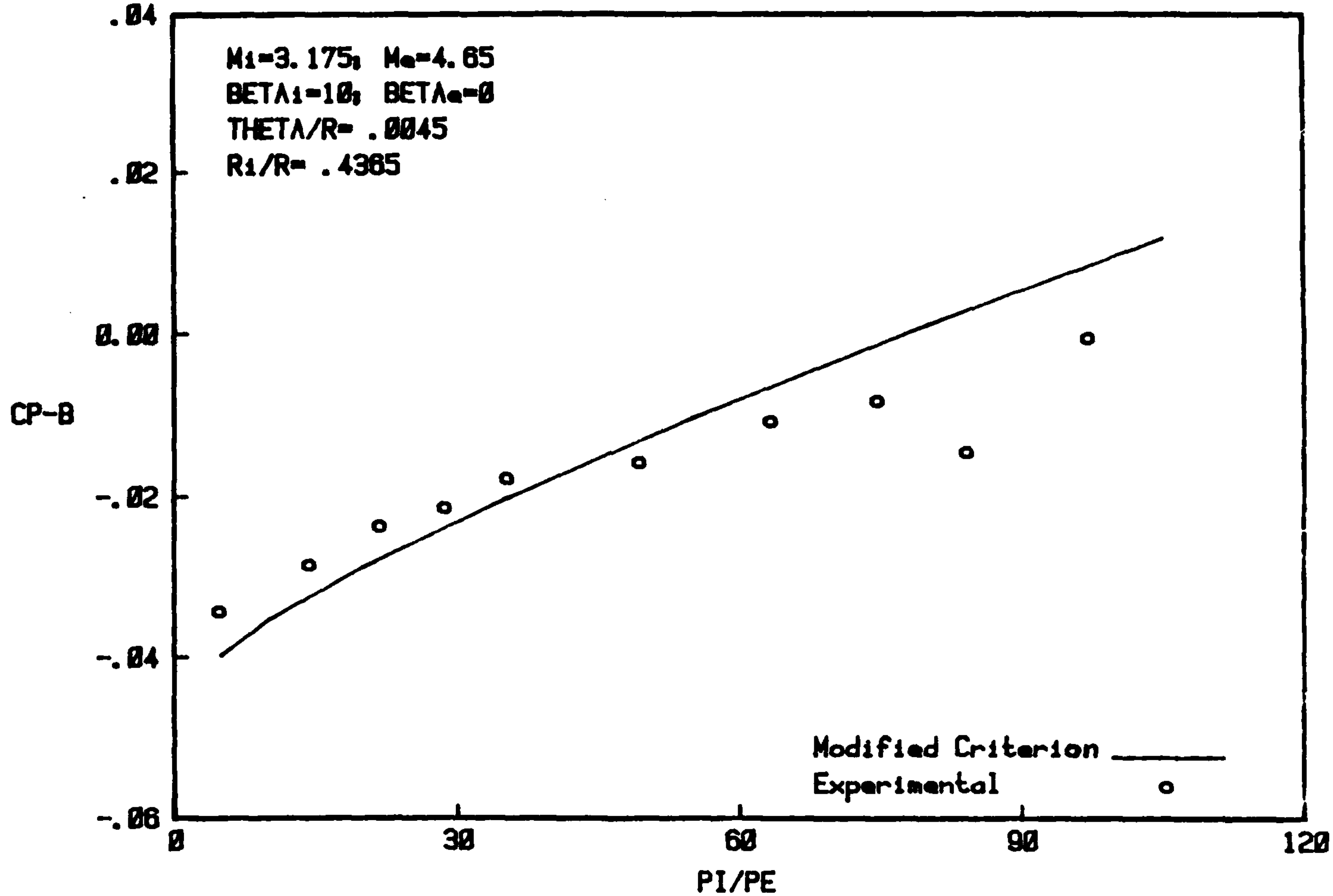

Figure 69, Comparison of calculated base pressures with experimental data from reference 30, (figure 10d), single jet, $M_\infty = 4.65$.

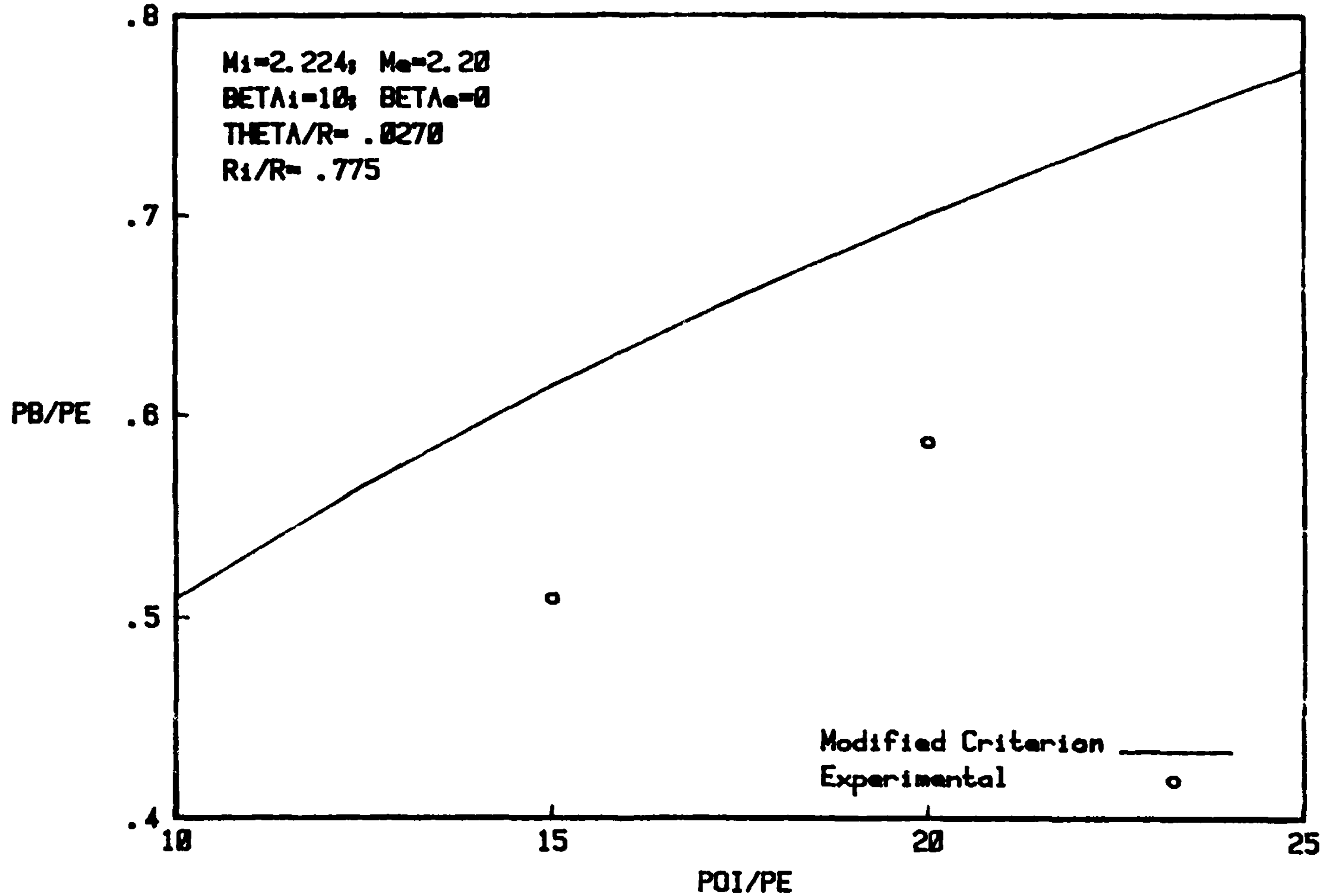

Figure 70. Comparison of calculated base pressures with experimental data from reference 31, (figure 12a), no bleed.

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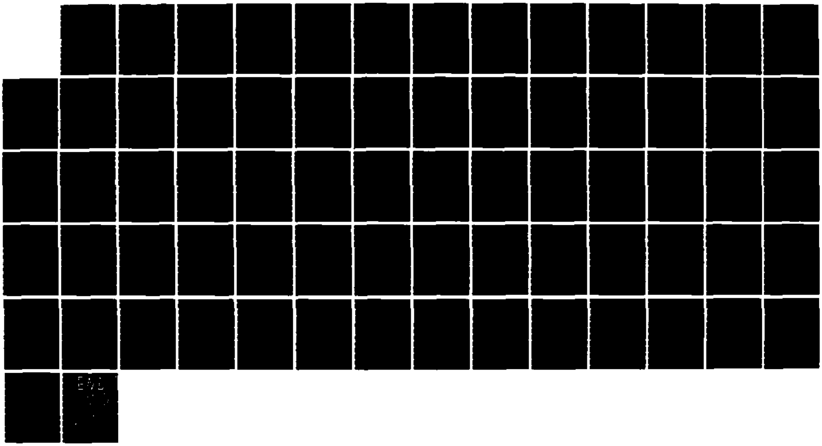

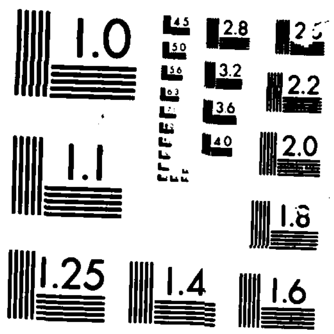

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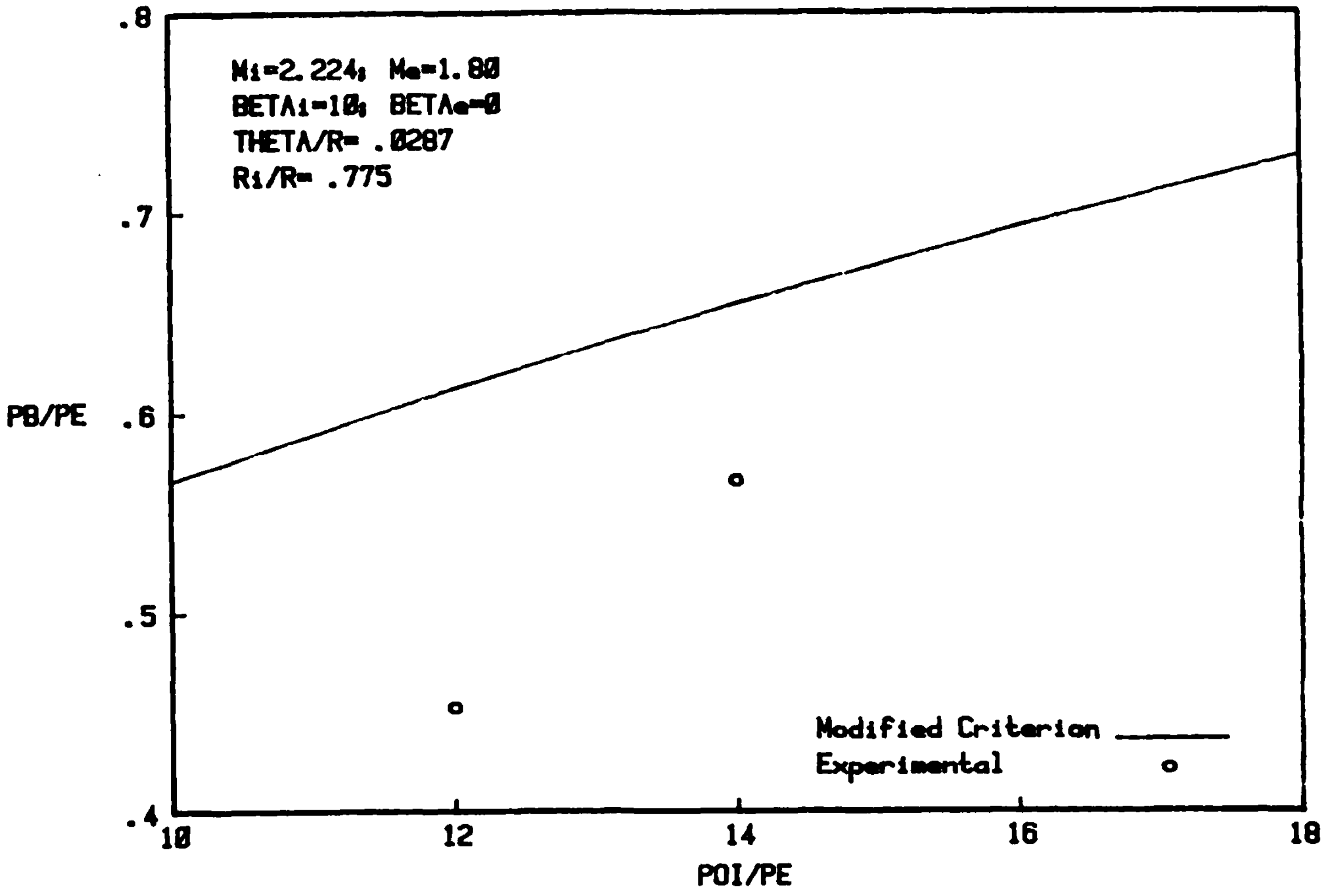

Figure 71. Comparison of calculated base pressures with experimental data from reference 31, (figure 12b), no bleed.

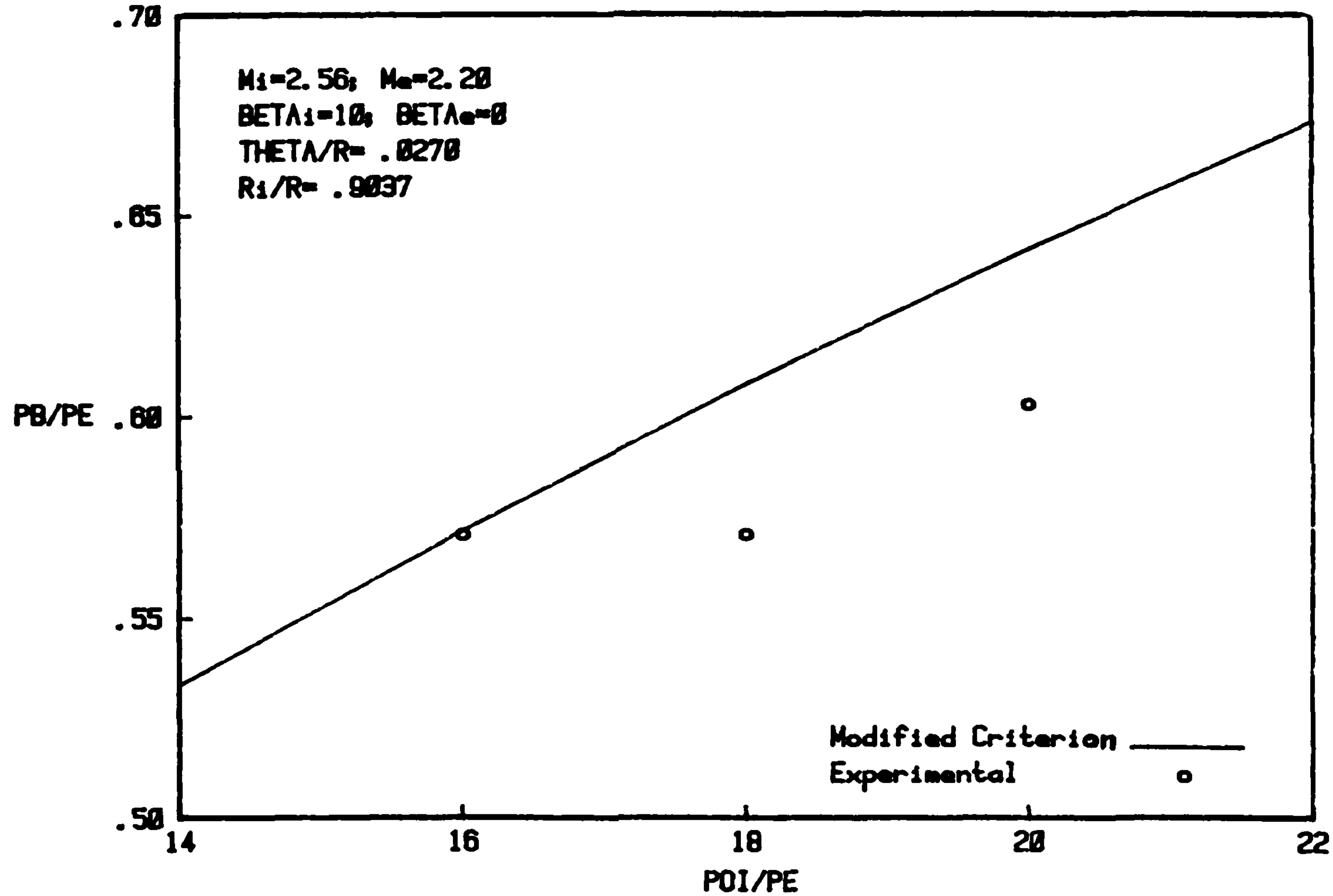

Figure 72. Comparison of calculated base pressures with experimental data from reference 31, (figure 14a), no bleed.

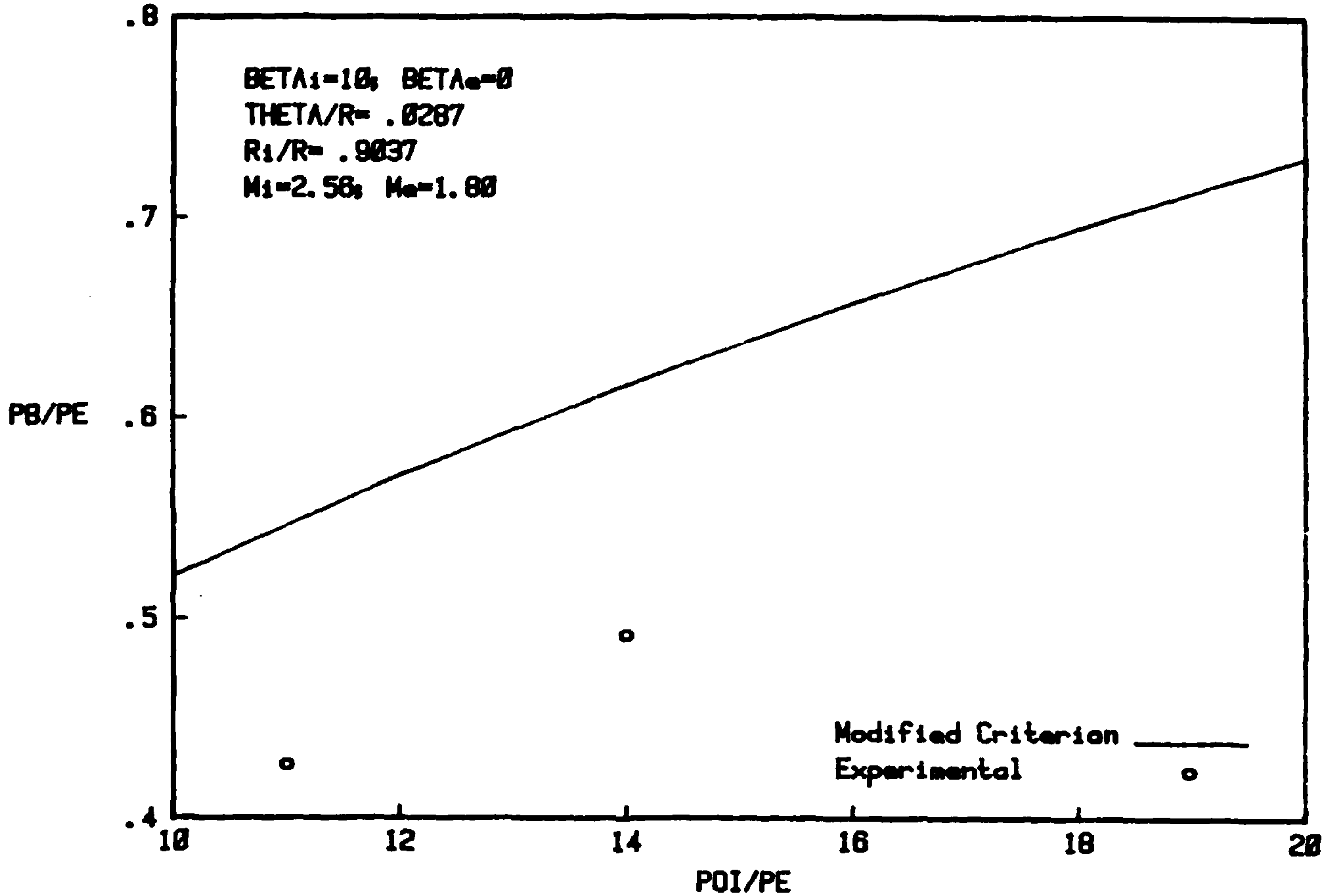

Figure 73. Comparison of calculated base pressures with experimental data from reference 31, (figure 14b), no bleed.

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GLOSSARY

Symbols	Definition
C_q	General bleed coefficient
C	Crocco number (U/U_{max})
F	Two-dimensional to axisymmetric spread rate ratio
I_1	Integral defined by Equation C-38 of Reference 17
I_2	Integral defined by Equation C-39 of Reference 17
L	Total length of mixing layer
m	Mass bleed
M	Mach number
P	Pressure
T	Temperature
U	x-component of the velocity within the shear layer or boundary layer
x_o	Mixing layer origin shift due to upstream boundary layer
x, y	Intrinsic coordinates in the two-dimensional mixing region
ε	Modifying bleed coefficient
γ	Ratio of the specific heats
Λ	Stagnation temperature ratio (see Equation 32)
η	Dimensionless coordinates in the mixing region [$\sigma y(x_o + x)$]
$\bar{\psi}$	Critical reattachment angle for the no bleed case
ψ	Critical reattachment angle
ρ	Density
σ	Spread rate or mixing parameter
θ	Boundary layer momentum thickness
ω	PRANDTL-Meyer function

GLOSSARY

Subscripts	Definition
AX	Axisymmetric
a	Adjacent inviscid flow
b	Adjacent quiescent region
B	Base Region
d	Discriminating streamline
o	Stagnation conditions
R	Reattachment conditions
R_a	Upper edge of shear layer
R_b	Lower edge of shear layer
2-D	Two-Dimensional

APPENDIX A

DEFINITION OF PERKIN-ELMER INTERACTIVE SCREEN CUES

AND PROGRAM INPUT DATA

The current version of the program is configured to either (1) read part of the data in an interactive mode from a terminal and part of the data from a Namelist data file or (2) to read all of the data in an interactive mode from a terminal. Data file input was found to be an efficient way to run the program when multiple cases were to be run with perhaps only one (1) input variable changed. For single case runs, the interactive mode is the most efficient way to run the program. The Namelist input file is name DATA, and the definition statement is

```
NAMELIST/DATA/NPRINT, NSHAPE, X1E, R1E, X2E, R2E, BETD2E, EMNE, X1I,
     R1I, BETD1I, GCI, GAMMAI, EMN1I, TROEI, KPRESR
```

Definitions of these variables, with the exception of NPRINT is given with the appropriate cue below. NPRINT is an output control parameter defined as follows:

NPRINT = -1, Input data and base pressure solution printed
NPRINT = 0, Input data, iterations and solution printed
NPRINT = +1, Input data, iterations with constant pressure boundary data, and solution printed
NOTE: In the total interactive mode, NPRINT = -1.

Cues which appear in the program are listed and the input quantity defined in the order in which they appear in the program. Where data is optional, depending on other input data, notes are included explaining the requirement or option.

```
CUE:  ENTER INPUT OPTION CHOICE, 1 = FILE  2 = TERMINAL
      READ (5, 72) INOPT
      FORMAT (I1)
      INOPT = INPUT DEVICE SELECTOR
```

CUE: ENTER NRCMP RECOMPRESSION CHOICE

0 = EMPIRICAL RECOMP COEFF AFTER ADDY OR WHITE

1 = KORST APPROXIMATION OF PAGE CRITERION

2 = CORRECT PAGE CRITERIA CALCULATED ITERATIVELY

3 = ONERA ANGULAR REATTACHMENT CRITERION

4 = ONERA CRITERIA MODIFIED FOR 2-STREAM REATTACK

5 = AS 4, SECOND ORDER CORRECTION FOR PHID

6 = AS 4, NONLINEAR TREATMENT (RECOMP = 1.NEC.)

READ (5, 13) NRCMP

FORMAT (I1)

NOTE: Only options 0, 3, 4, and 5 are operational. It is suggested that if the Addy or White empirical recompression coefficient is used that the boundary layer momentum thicknesses be set equal to zero.

The following cue appears only if NRCMP = 0 is chosen, then

CUE: ENTER RECOMP

READ (5, 6) RECOMP

FORMAT (F6.4)

RECOMP = SELECTOR FOR RECOMPRESSION COEFFICIENT

NOTE: If RECOMP = 0., a value is calculated for RECOMP from Addy's or White's empirical equations. If a finite value of RECOMP is input, it is used for the calculation.

CUE: ENTER ALPHANUMERIC HEADING - 20A4

READ (5, 10) (A(I),I=1,20)

FORMAT (20A4)

A(I) = ANY ALPHANUMERIC PROBLEM DESCRIPTION

CUE: ENTER NSHIFT

READ (5, 9) NSHIFT

FORMAT (I1)

NSHIFT = 0, ONERA ORIGIN SHIFT (RECOMMENDED)

NSHIFT = 1, SHEAR LAYER AND BOUNDARY LAYER MOMENTUM THICKNESSES MATCHED

NOTE: If a Namelist data file is to be used, the next cue to appear is the cue for the number of pressure ratio cases to be run. For the interactive mode, the following cue appears.

AFTERBODY SHAPE PARAMETERS

0 - CYLINDRICAL AFTERBODY

CUE: 1 - OGIVE BOATTAIL

2 - PARABOLIC BOATTAIL

3 - CONICAL BOATTAIL OR FLARE

ENTER AFTERBODY SHAPE PARAMETER - I1

READ (5, 13) NSHAPE

FORMAT (I1)

NSHAPE = PARAMETER DEFINING THE AFTERBODY SHAPE

MESSAGE: BODY AND NOZZLE DIMENSIONS ARE RELATIVE

THEY CAN BE INCHES, FEET, OR CALIBERS

"X" DIMENSIONS ARE POSITIVE AFT

CUE: ENTER "X" AT BODY BASE

READ(5, 11) X1E

FORMAT (4F10.4)

X1E = LONGITUDINAL COORDINATE OF POINT WHERE SEPARATION OF THE EXTERNAL STEAM OCCURS

CUE: ENTER RADIUS AT BODY BASE

READ(5, 11) R1E

FORMAT (4F10.4)

R1E = RADIAL COORDINATE OF POINT WHERE SEPARATION OF THE EXTERNAL STREAM OCCURS

The following three cues are dependent upon the value of NSHAPE. If NSHAPE = 1, 2, or 3, these cues appear. If NSHAPE = 0, they do not appear and the cue for the free stream Mach number appears.

CUE: ENTER "X" AT START OF BOATTAIL

READ(5, 11) X2E

FORMAT (4F10.4)

X2E = INITIAL LONGITUDINAL COORDINATE OF THE BOATTAIL

CUE: ENTER RADIUS AT START OF BOATTAIL

READ(5, 11) R2E

FORMAT (4F10.4)

R2E = INITIAL RADIAL COORDINATE OF THE BOATTAIL

CUE: ENTER SLOPE AT START OF BOATTAIL - DEG

READ (5, 11) BETD2E

FORMAT (4F10.4)

BETD2E = INITIAL BOATTAIL ANGLE (IN DEGREES) AT (X2E, R2E) COUNTER-CLOCKWISE FROM X-AXIS IS POSITIVE.

CUE: ENTER FREE STREAM MACH NUMBER

READ (5, 11) EMNE

FORMAT (4F10.4)

EMNE = EXTERNAL FREE STREAM MACH NUMBER

CUE: ENTER "X" AT END OF NOZZLE

READ (5, 11) X1I

FORMAT (4F10.4)

X1I = LONGITUDINAL COORDINATE OF POINT WHERE SEPARATION OF THE INTERNAL STREAM OCCURS

CUE: ENTER NOZZLE EXIT RADIUS

READ (5, 11) R1I

FORMAT (4F10.4)

R1I = RADIAL COORDINATE OF POINT WHERE SEPARATION OF THE INTERNAL STREAM OCCURS

CUE: ENTER NOZZLE EXIT ANGLE - DEG

READ (5, 11) BETD1I

FORMAT (4F10.4)

BETD1I = FLOW ANGLE (IN DEGREES) AT (X1I, R1I) COUNTER-CLOCKWISE IS POSITIVE

CUE: ENTER NOZZLE GAS CONSTANT - LBF/LBM R

53.34 FOR AIR

READ (5, 11) GCI

FORMAT (4F10.4)

GCT = GAS CONSTANT FOR THE INTERNAL STREAM

CUE: ENTER NOZZLE GAMMA - 1.4 FOR AIR

READ (5, 11) GAMMAI

FORMAT (4F10.4)

GAMMAI = RATIO OF SPECIFIC HEATS FOR THE INTERNAL GAS

CUE: ENTER NOZZLE EXIT MACH NUMBER

READ (5, 11) EMN1I

FORMAT (4F10.4)

EMN1I = MACH NUMBER AT (X1I, R1I)

```
CUE:  ENTER EXTERNAL TO INTERNAL STREAM STAGNATION TEMPERATURE RATIO
         - TOE/TOI
      READ (5, 11) TROEI
      FORMAT (4F10.4)
      TROEI = STAGNATION TEMPERATURE RATIO OF STREAMS, TOE/TOI

CUE:  ENTER NUMBER OF CASES - I1
      READ (5, 13) NCASE
      FORMAT (I1)
      NCASE = NUMBER OF PRESSURE RATIOS, P1I/PE OR POI/PE, FOR WHICH
              BASE PRESSURE CALCULATIONS ARE TO BE MADE FOR A GIVEN
              SET OF CONDITIONS AND GEOMETRY

CUE:  ENTER TYPE OF PRESSURE RATIO INPUT
        0 FOR INTERNAL STATIC/EXTERNAL STATIC PRESSURE
        1 FOR INTERNAL STAGNATION/EXT STATIC PRESSURE
      READ (5, 13) KPRESR
      FORMAT (I1)
      KPRESR = 0, PR1IE (P1I/PE) IS INPUT, AND PROIE IS CALCULATED.
               1, PROIE (POI/PE) IS INPUT, AND PR1IE IS CALCULATED.
```

The follwing cues depend upon the value of KPRESR. If KPRESR = 0, then

```
CUE:  ENTER PJ/PF
      READ (5,11) PRATIO
      FORMAT (4F10.4)
      PRATIO = PRESSURE RATIO (P1I/PE = PR1IE) FOR CASE 1.
```

If KPRESR = 1, then

```
CUE:  ENTER POJ/PF'
      READ (5, 11) PRATIO
      FORMAT (4F10.4)
      PRATIO = PRESSURE RATIO (POI/PE = PROIE) FOR CASE 1.
```

CUE: ENTER BOUNDARY LAYER MOMENTUM THICKNESS AT BODY BASE

READ (5, 11) BLMTE

FORMAT (4F10.4)

BLMTE = EXTERNAL FLOW BOUNDARY LAYER MOMENTUM THICKNESS AT SEPARATION POINT - SAME UNITS AS BODY DIMENSIONS

CUE: ENTER BOUNDARY LAYER MOMENTUM THICKNESS AT NOZZLE EXIT

READ (5, 11) BLMTI

BLMTI = INTERNAL FLOW BOUNDARY LAYER MOMENTUM THICKNESS AT NOZZLE EXIT PLANE - SAME UNIT AS BODY DIMENSIONS

The cues PJ/PR or POJ/PJ along with the cues for BLMTE and BLMTI reappear after the solution for each pressure ratio is obtained until the NCASE solutions have been completed. After the solution for the last pressure ratio has been completed, the following cue appears.

CUE: DO YOU WISH TO MAKE ANOTHER RUN? YES = 1, NO = 0

READ (5, *) IRUN

FREE FORMAT

IRUN = 0, NORMAL PROGRAM EXIT

1, RETURN TO FIRST CUE

Cues are typed above exactly as they appear on the screen and in the order in which they appear. For the input data which are real numbers, a format cue in the form of XXXXX.XXXX also comes in the screen. Mnemonics for the input data are the ones used in Reference 4 and the definitions are basically the same as those presented in Reference 4.

APPENDIX B

COMPUTER PROGRAM LISTING

```
C      PROGRAM TSAMPP(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,
C     1   TAPE7=PUNCH)
C      T W O - S T R E A M   A X I S Y M M E T R I C   B A S E
C      P R E S S U R E   P R O G R A M ,   T S A M P P - 2 .
C      A F T E R B O D Y   O P T I O N A L   B E F O R E
C      PROGRAM HAS BOTH INTERNAL AND EXTERNAL STREAM
C      BOUNDRY LAYER EFFECTS INCLUDED IN THE FORMAT OF
C      EFFECTIVE MASS BLEED AND A MIXING LAYER ORIGIN SHIFT.
C
C*****MASTER REQUIRES --- INOUT, OUT1M, OUT2M, ACPMS, CROSS, TJMIX,
C                          ITER.  THE VARIOUS SUBROUTINES CALL OTHERS.
C
C
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1          P3(5), A(20), DATA(10,2), BPTI(5,30), BPTE(5,30)
      COMMON PMB, CHARI, CHARE, P1, P2, P3
      COMMON /ANGLES/THETA1,THETA2,THETAS,F1,F2
      COMMON  /ERFVP/ PHI(350)
      COMMON  /DATAIO/  GCI,GAMMAI,EMSII,XII,RII,BETAII,
     1                   GCE,GAMMAE,EMS1E,X1E,R1E,BETA1E,PRO1OE,
     2                   TRUEI,PRIIE,PECOMP,A,EMNII,PRIOI,EMNIE,PRIOIE,
     3                   NPRINT,NCAS1,NCASE,BLDRO,ENGRO,RE,EMNE,FREOE,
     4                   NPUNCH,PROEOI,PROIE,POIFOI,NSHAPE,NPTSE,PRIIIE,
     5                   NDEFLT,BLMTE,BLMTI
      COMMON /C*1/CDHT,XFIX,RFIX,NSEP,SEPRIS,XTEST,EEE,SEPR,DELTA
      COMMON /C*2/X2E,R2E
      COMMON /C*3/SIGMF1,SIGMF2,NRCMP,NSIGMA,NBLEED,XPAGE,NSHIFT,
     1            THPSLP,RECMP1,RECMP2
      COMMON /ICROS/ICROSS,BPR
C
      EMNMSF(EMS,GAMMA)=SQRT(((2.0*(EMS**2))/(GAMMA+1.0))/
     1                  (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))   )
      ATFLMS (EMS,GAMMA)=SQRT  (2.0*GAMMA/(GAMMA+1.0))*
     1                  (EMS/(1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2)))
      NDEFLT = 1
      NCASE=0
    8 NCAS1=0
   10 IF(NCAS1.EQ.NCASE) NCAS1=0
C
C      *****READ/WRITE BASE PRESSURE CASE INPUT DATA*****
C
      CALL  INOUT
      IF(NCASE.EQ.0)  GO TO 8
C*****LIMITING RADII FOR (I) AND (E) STREAMS ARE SPECIFIED HERE.
      RLI=1.5*R1E
      RLE=0.5*RII
C*****INITIALIZATION OF BASE PRESSURE ITERATION LOOP.
      DTHBOI=(1.0-TRUEI)/2.0
      BPR=0.50
      BPRL=0.0
C*****EMPIRICAL SEPARATION PRESSURE RATIO EXPRESSION FROM---
C      ZUKOSKI, AIAA JOURNAL, OCTOBER 1967, VOL. 5, NO. 10, PP.1746-1753.
C      PRSEP = 1.0 + 0.365*(MACH NO.).
C*****EXTERNAL/INTERNAL FLOWS SEPARATION PRESSURE RATIOS.
      PRS1E = 1.0 + 0.365*EMN1E
      PRS1I = 1.0 + 0.365*EMNII
      BPRR = PRS1E
      IF (((PRS1I/PRS1E)*PRI1IE) .LT. 1.0)   BPRR = PRS1I*PRI1IE
      NOSOLN=0
      NOSMAX = 10
      IBPR=1
      IBPRMX=15
```

```
      NBPR=1
      NTYPE=1
      IF(ABS (TROFT-1.0).LE.1.0E-03)  NTYPE=3
   20 IF (IBPR .LE. IBPRMX)    GO TO 40
C
      WRITE (3,22)              BPRL, BPR, BPRR
   22 FORMAT (//, 15X,
     1 53H ***MAXIMUM NO. OF BASE PRESS. ITERATIONS EXCEEDED*** ,/,
     2 15X,10H ***BPRL = ,F7.4,2X,7H BPR = ,F7.4,2X,
     3 7H BPRR = ,F7.4,4H ***,/  )
C
      IF((ABS(BPR-BPRR).LE.1.0E-3).OR.(BPR.GT.BPRR))  WRITE(3,24)
   24 FORMAT (15X,33H *** PROBABLE FLOW SEPARATION FOR    ,
     1          20H SPECIFIED DATA  ***   ,/)
C
      WRITE  (3,26)
   26 FORMAT (15X,
     1          53H ***************************************************** /)
      GO TO 260
C
C*****CHECK THAT BPR IS IN THE SOLUTION RANGE, (BPRL,BPRR).
   40 IF ((BPR .GE. BPRL) .AND. (BPR .LE. BPRR))   GO TO 50
      BPR=(BPRL+BPRR)/2.0
C*****CALCULATE THE EXPANSION PRESSURE RATIOS FOR THE BOUNDARY CALCS.
   50 PRB1E = BPR
      PRBO1E = BPR*PR1O1E
      PRBOI=PRBO1E*PO1EOI
      PRB1I=PRBOI/PR1OI
      PRBE=(PRBO1E*PRO1OE)/PREOE
      PRBOE=PRBO1E*PRO1OE
      CP=2.0*((PRBE-1.0)/(GAMMAE*(EMNE**2)))
      CD = -CP*((R1E**2-R1I**2)/RE**2)
C*****WRITE THE CURRENT TRIAL SOLUTION DATA.
      CALL OUTIM(IBPR,A,EMN1I,PR1OI,PRBOI,PRB1I,PROEOI,TROEI,PR1IE,
     1            EMN1E,PR1O1E,PRBO1E,PRB1E,EMNE,PREOE,PRBOE,PROIE,
     2            PRBE,NPRINT,BLDRO,ENGRO,NSHAPE,NRCMP)
C*****THE INTERNAL CONSTANT PRESSURE BNDRY IS CALCULATED FOR (PB/POI).
      CALL ACPBS(GAMMAI,EMS1I,PRBOI,X1I,R1I,BETA1I,RLI,IBPR,NPTSI,
     1            NPRINT,1,LIMITI,BPTI,NSHAPE)
C*****THE EXTERNAL CONSTANT PRESSURE BNDRY IS CALCULATED FOR (PB/POIE).
      CALL ACPBS(GAMMAE,EMS1E,PRBO1E,X1E,R1E,BETA1E,RLE,IBPR,NPTSE,
     1            NPRINT,2,LIMITE,BPTE,NSHAPE)
C*****IF IMPINGEMENT OCCURS, THE IMPINGEMENT POINT AND THE FLOW
C     PROPERTIES DOWNSTREAM OF THE RECOMPRESSION SHOCK SYSTEM ARE FOUND.
C
      CALL  CROSS(GAMMAI,BPTI,LIMITI,GAMMAE,BPTE,LIMITE,
     1             NIC,NEC,NSTOP,TJMLI,TJMLE,PRSHOK,NPRINT)
      IF(RECOMP*PRSHOK .LT. 1.0 .AND. NSTOP .EQ. 1)  NSTOP=2
      GO TO (80,82,84), NSTOP
C
C     CALCULATE THE BOUNDRY LAYER MOMENTUM THIKNESS AFTER
C     THE BASE EXPANSION IS COMPLETED USING THE RESULTS
C     OF NASH PUBLISHED IN R.& M. NO.3344,1963.
C
   80 BLMTEB=BLMTE*(EMN1E/EMNMSF(BPTE(3,NEC),GAMMAE))**2/PRB1E
     1       *WTFLMS(EMS1E,GAMMAE)/WTFLMS(BPTE(3,NEC),GAMMAE)
      BLMTIB=BLMTI*(EMN1I/EMNMSF(BPTI(3,NIC),GAMMAI))**2/PRB1I
     1       *WTFLMS(EMS1I,GAMMAI)/WTFLMS(BPTI(3,NIC),GAMMAI)
C
      ITC=0
      GO TO 90
C*****NO INVISCID SOLUTION TRIAL CASES.
C     NUMBER OF NO SOLUTION TRIALS = NOSMAX.
```

```
C******NO SOLUTION---NO IMPINGEMENT OR INADMISSIBLE SHOCK SOLUTION.
   82  BPRR=BPR
       GO TO 86
C******NO SOLUTION---SHOCK SYSTEM DOESNT EXIST FOR TRIAL VALUE OF BPR.
   84  BPRL=BPR
   86  BPR=(BPRL+BPRR)/2.
       NOSOLN=NOSOLN+1
       IF(NOSOLN.LE.NOSMAX)  GO TO 20
C*****MAXIMUM NUMBER OF NO-SOLUTION TRIALS EXCEEDED.
C
       WRITE (3,88)
   88  FORMAT(//,
      1 15X,49H ***MAXIMUM NO. OF NO SOLUTION TRIALS EXCEEDED** ,/,
      2 15X,49H ************************************************ /)
       GO TO 260
C
C*****START BASE PRESSURE AND TEMPERATURE RATIO ITERATION LOOPS.
   90  TRBOI=TROEI
       IE=1
       NE=1
  100  TRBOE=TRBOI/TROEI
       ITC=ITC+1
C*****CALCULATION AND OUTPUT OF TURBULENT MIXING RESULTS.
       CALL  TJMIX(GAMMAI,GCI,BPTI(3,NIC),TRBOI,TJMLI,
      1            GAMMAE,GCE,BPTE(3,NEC),TRBOE,TJMLE,
      2            RII,EMSII,BETAII,BPTI(2,NIC),PRSHOK,
      3            PUIEOI,TROEI,RECOMP,BLDR,ENGR,
      4            BLMTIB,BLMTEB,ITC)
C
C      CALCULATE THE BOUNDRY BLEED RATES RATIOD TO
C      THE NOZZLE MASS FLOW RATE
C
       BLDROE=BLMTEB/RII*RIE/RII*PRBII*(1.0+COS(BETAII))*
      1         SQRT(GCI/GCE/TROEI)*WTFLMS(BPTE(3,NEC),GAMMAE)/
      2        WTFLMS(EMSII,GAMMAI)
       BLDROI=BLMTIB/RII*PRBII*(1.0+COS(BETAII))*
      1        WTFLMS(BPTI(3,NIC),GAMMAI)/WTFLMS(EMSII,GAMMAI)
       BLDRO=BLDROE+BLDROI
       ENGROE=BLDROE*GAMMAE*(GAMMAI-1.0)*TROEI*(GCE/GCI)/(GAMMAI*
      1(GAMMAE-1.0))
       ENGROI=BLDROI
       ENGRO=ENGROE+ENGROI
       CALL OUT2M(PRBE,PRBII,PROEOI,TRBOE,TRBOI,TROEI,PROIE ,PRIIE,
      1             BLDR,ENGR,NPRINT,CP,CD,BLDRO,ENGRO)
C*****SET-UP ITERATION LOOPS TO FIND---
C      NTYPE=1 (NONISOENERGETIC), TRBOI SO THAT ENGR=ENGRO.
C      NTYPE=2 (NONISOENERGETIC), TRBOI SO THAT BLDR=BLDRO.
C      NTYPE=3 (ISOENEGETIC), CONTINUE TO BASE PRESSURE ITERATION LOOP
C                             TO FIND BPR SO THAT BLDR=BLDRO.
C
       GO TO (124,126,210), NTYPE
C*****TRBOI ITERATION LOOPS FOR THE NON-ISOENERGETIC CASE.
  124  VAR=(ENGR-ENGRO-ENGRO)
       GO TO 130
  126  VAR=(BLDR-BLDRO-BLDRO)
  130  GO TO (140,142), NE
  140  DATA(IE,1)=TRBOI
       DATA(IE,2)=VAR
C*****ITERATION FOR TRBOI SUCH THAT ENGR=ENGRO OR BLDR=BLDRO.
C      (NOTE THAT TRBOI IS RESTRICTED TO THE RANGE (TROEI,1.0)   )
C
  142  CALL ITER(TRBOI,DTRBOI,1.0E-4,1.0,VAR,0.0, 1.0E-5,IE,NE,
      1           TRBOIN,VARN,TRBOIP,VARP,NSGNV1,NSGNV2)
```

```
      IF(TRBOI-1.0)150,150,160
 150  GO TO (100,100,200), NE
C*****EXTRAPOLATION, IF NECESSARY, FOR TEMPERATURE RATIO TRBOI
C     SUCH THAT ENGR=ENGRO OR BLDR=BLDRO.
C
 160  IE=IE-1
      IF(ABS (DATA(1,2))-ABS (DATA(IE,2)))  170,170,180
 170  I=1
      II=2
      GO TO 190
 180  I=IE-1
      II=IE
 190  RATIO=(DATA(II,1)-DATA(I,1))/(DATA(II,2)-DATA(I,2))
      TRBOI=DATA(I,1)-RATIO*DATA(I,2)
 200  GO TO (202,204), NTYPE
 202  TREO=TRBOI
      NTYPE=2
      GO TO 90
 204  TRBO=TRBOI
      NTYPE=1
C*****END TRBOI ITERATION LOOPS.
C*****CONTINUE THE BASE PRESSURE RATIO (BPR) ITERATION LOOP TO FIND
C     BPR SUCH THAT DVAR=0.
C*****FOR THE NON-ISOENERGETIC CASE.
      DVAR=(TREO-TRBO)
      GO TO 214
C*****FOR THE ISOENERGETIC CASE.
 210  DVAR=(BLDRO+BLDRO-BLDR)
 214  SIGN=DVAR/ABS(DVAR)
      IF(SIGN)  218,218,222
 218  BPRR=BPR
      GO TO 226
 222  BPRL=BPR
 226  IF(IBPR-1)  230,230,234
 230  DBPR=(BPRR-BPRL)/2.
      GO TO 238
 234  SIGN=1.0
      DBPR=-((BPR-BPR1)/(DVAR-DVAR1))*DVAR
 238  BPR1=BPR
      DVAR1=DVAR
C*****ITERATION FOR BPR SUCH THAT DVAR=0.
      CALL ITER(BPR,DBPR,1.0E-4,SIGN,DVAR,0.0,1.0E-5,IBPR,NBPR,
     1          BPRN,DVARN,BPRP,DVARP,NSGNB1,NSGNB2)
      GO TO (20,20,242), NBPR
C*****SOLUTION FOUND.
 242  GO TO (250,250,254), NTYPE
C*****WRITE SOLUTION DATA.
C
 250  WRITE (3,252)
 252  FORMAT(//, 20X, 32H ***NON-ISOENERGETIC SOLUTION*** ,/,
     1          20X, 32H ******************************** ,//)
      GO TO 258
C
 254  WRITE (3,256)
 256  FORMAT(//,  27X, 28H ***ISOENERGETIC SOLUTION*** ,/
     1            27X, 28H ************************      /)
C
 258  CALL OUT2 (PRBE,PRBII,PROEOI,TRPOE,TRBOI,TROEI,PROIE ,PRIIE,
     1          BLDR,ENGR,1,CP,CD,BLDRO,ENGRO)
      IF(NPUNCH) 285,285,270
C*****PUNCH SOLUTION DATA.
 260  IF(NPUNCH) 285,285,265
C
```

```
 265  WRITE (7,267)            PROIE, PR1IE, PRMF
 267  FORMAT(2F11.4,5X,11HNO SOLUTION, 5X, 9H PR/PE  = F8.5)
      GO TO 280
C
 270  R1IE=R11/RE
C*****CT---T/QA (THRUST COEFFICIENT).
      CT = ((R1IE**2)/(0.5*GAMMAE*(EMNIE**2)))*(PR1IE*(1.0+GAMMA1*
     1       (EMN1I**2))-1.0)
C*****RMF---JET-TO-FREESTREAM MOMENTUM FLUX RATIO.
      RMF = (GAMMA1*(EMN1I**2)*(R1IE**2)*PR1IE)/(GAMMAE*(EMNE**2))
C
      WRITE (7,272)            PROIE,PR1IE,PRMF,CP,CD,RMF,CT
 272  FORMAT(2F11.4,5F11.5)
C
 280  IF (NCAS1 .EQ. NCASE) WRITE (7,282) (A(I),I=1,20)
 282  FORMAT (    20A4,/,80H++++++++++++++++++++++++++++++++++++++++++++++
     1++++++++++++++++++++++++++++++++++)
 285  IF (NCAS1 .GE. NCASE) GO TO 290
C
C     *****GO TO NEXT CASE*****
      GO TO 10
C
290   CALL BEEP(10,5)
      WRITE (5,300)
 300  FORMAT(1H5,'DO YOU WISH TO MAKE ANOTHER RUN? YES=1,NO=0')
      READ (5,*) IRUN
      IF (IRUN .EQ. 1) GO TO 10
      END
C*********************************************************************
C
      SUBROUTINE OUT1M(I,A,EMN1I,PR1O1,PRBOI,PRB1I,PROEOI,TROEI,PR1IE,
     1                 EMN1E,PR1O1E,PRBO1E,PRB1E,EMNE,PREOE,PRBOE,PROIE,
     2                 PRBE,NPRINT,BLDRO,ENGRO,NSHAPE,NRCMP)
C
C*****SUBROUTINE WRITES OUT HEADINGS AND CURRENT DATA USED FOR THE
C     INVISCID FLOW FIELD CALCULATIONS.
C
C     ***VARIABLES***
C
C     I      = I-TH VALUE OF THE INPUT BASE PRESSURE RATIO.
C     A      = HEADING CARD DATA.
C
C     *** FOR EITHER STREAM AT (1I), (1E), OR (E--FREESTREAM).
C
C     EMN    = MACH NUMBER.
C     PREO   = PRESSURE RATIO, PE/PO.
C     PR1O   = PRESSURE RATIO AT (1), P1/PO.
C     PRBO   = BASE PRESSURE RATIO, PB/PO.
C     PRB1   = BASE PRESSURE RATIO, PB/P1.
C
C     PR1IE = INPUT STATIC PRESSURE RATIO OF STREAMS, P1I/PE.
C     TROEI = STAGNATION TEMPERATURE RATIO OF STREAMS,  TOE/TOI.
C     PROEOI= STAGNATION PRESSURE RATIO OF STREAMS, POE/POI.
C     NPRINT= SEE SUBROUTINE *INOUT*.
C     BLDRO,ENGRO = SPECIFIED VALUES OF THE BLEED AND ENERGY RATIOS.
C     NSHAPE= 0, NO BOATTAIL.
C            = 1,2 OR 3---OGIVE, PARABOLIC, OR CONICAL BOATTAILS.
C
      DIMENSION  A(20)
      IF(NPRINT) 107,107,99
C
  99  WRITE (3,100)            (A(J),J=1,20),NRCMP,PR1IE,TROEI,PROEOI,
     1                 PROIE,BLDRO,ENGRO,I
```

```
 100  FORMAT(1H1, 5X, 20A4,3X,9H NRCMP = ,I1,//,
     1 15X,51H *********TWO-STREAM BASE PRESSURE PROGRAM**********, //,
     2 27X,25H ******CURRENT DATA******,//,
     3 15X,11H PII/PE  = F9.4,17X,11H TOE/TOI = F8.5,//,
     4 15X,11H POE/POI = F9.5,17X,11H POI/PE  = F8.3,//,
     5  15X,9H BLDRO = E12.5, 16X, 9H ENGRO = E12.5,//,
     6 22X,31H TRIAL BASE PRESSURE RATIO NO. ,I4,/,
     7 22X,31H ***** **** ******** ***** *** ,//)
C
      WRITE (3,101)           EMN1I,PP1OI,PRBOI,PRBII,
     1                        EMN1E,PP1OIE,PRBOIE,PRBIE
 101  FORMAT(28X,22H ***INTERNAL STREAM***, //,
     1 15X,8H EMN1I = F7.4,25X,10H PII/POI = F8.6,//,
     2 15X,9H PB/POI = F8.6,23X,9H PB/PII = F8.6,//,
     3 28X,22H ***EXTERNAL STREAM***, //,
     4 15X,8H EMN1E = F7.4,25X,11H PIE/POIE = F8.6,//,
     5 15X,9H PB/POIE= F8.6,23X,9H PB/PIE = F8.6,//)
C
      WRITE (3,102)           EMNE,PREOE,PRBOE,PRBE
 102  FORMAT(30X,17H ***FREESTREAM*** , //,
     1 15X,7H EMNE = F7.4, 23X, 9H PE/POE = F8.6, //,
     2 15X, 9H PB/POE = F8.6, 20X, 9H PB/PE  = F8.6,//)
C
      IF(NSHAPE) 103,103,105
C
 103  WRITE (3,104)
 104  FORMAT(21X,32H *** NO BOATTAIL BEFORE BASE ***  , /)
      RETURN
C
 105  WRITE (3,106)           NSHAPE
 106  FORMAT(25X, 27H *** BOATTAIL --- NSHAPE = I1, 4H ***  ,/)
C
 107  RETURN
      END
C     ************************************************************
C
      SUBROUTINE INOUT
C
C*****SUBROUTINE READS IN THE INPUT DATA AND THEN CALCULATES THE INPUT
C     DATA FOR THE MASTER PROGRAM.  THE IDENTIFICATION, HEADINGS AND
C     INPUT DATA ARE THEN WRITTEN OUT.
C
C
C     ***VARIABLES***
C
C
C     FOR EITHER THE INTERNAL  (I)  OR EXTERNAL  (E)  STREAM
C
C     BETD1  = FLOW ANGLE (IN DEGREES) AT (X1,R1).  CCW IS POSTIVE.
C              ( BETD1I IS (+) AND BETD2E IS (+/-) ).
C     BETD2E = INITIAL AFTERBODY ANGLE AT (X2E,R2E).
C     BLDRO  = SPECIFIED VALUE OF THE BLEED RATIO.
C     BLMTE  = EXTERNAL STREAM BOUNDRY LAYER MOMENTUM THICKNESS
C     BLMTI  = INTERNAL STREAM BOUNDRY LAYER MOMENTUM THICKNESS
C     ENGRO  = SPECIFIED VALUE OF THE ENERGY RATIO.
C     EMNE   = EXTERNAL FREESTREAM MACH NUMBER.
C     EMS1I  = MACH STAR AT  (1I).
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     GC     = GAS CONSTANT   (LBF-FT/LBM-R)
C     INOPT  = 1, INPUT IS READ FROM NAMELIST DATA
C              2, INPUT IS INPUT AT TERMINAL DURING PROG. EXECUTION
C     KPRESR = 0, PR1IE IS INPUT, AND PRO1F IS CALCULATED.
C            = 1, PRO1F IS INPUT, AND PR1IE IS CALCULATED.
```

```
C      NCASE  = NUMBER OF PRESSURE RATIOS, PII/PE , FOR WHICH BASE
C               PRESSURE CALCULATIONS ARE TO BE MADE FOR A GIVEN SET OF
C               CONDITIONS AND GEOMETRY.
C      NDEFLT = 0, THE VARIABLES ARE RESET TO THE *DEFAULT CONFIGURATION*
C                  AFTER THE CASE (SET OF PRESSURE RATIOS) IS COMPLETED.
C             = 1, THE VARIABLES WILL NOT BE RESET AT UPON COMPLETION
C                  OF THE CASE.
C      NOTE --- CHANGING THE VALUE OF *NEDFLT* WILL FIRST AFFECT THE
C               CASE SUCCEEDING THE CASE IN WHICH IT IS CHANGED.
C      NPUNCH = 0, SUMMARY OUTPUT DATA NOT PUNCHED.
C      NPRINT = -1, INPUT DATA AND BASE PRESSURE SOLN PRINTED.
C      NSHAPE = 0, NO AFTERBODY.
C             = 1, OGIVE BOATTAIL.
C             = 2, PARABOLIC BOATTAIL.
C             = 3, CONICAL BOATTAIL OR FLARE.
C      PRIIE  = STATIC PRESSURE RATIO OF STREAMS, PII/PE.
C      PROEOI = STAGNATION PRESSURE RATIO OF STREAMS, POE/POI.
C      PROIE  = INTERNAL STREAM STAGNATION PRESSURE TO EXTERNAL STREAM
C               STATIC PRESSURE RATIO (NOZZLE CHAMBER TO FREESTREAM
C               STATIC PRESSURE RATIO), POI/PE.
C      RECOMP = RECOMPRESSION COEFFICIENT =0.0
C      NOTE --- IF THE INPUT VALUE OF RECOMP=0.0 ,AND,
C               1) NSHAPE=0, THEN RECOMP IS CALCULATED FROM
C                            EMPIRICAL EQUATION ON CARD NO. INOU2630.
C               2) NSHAPE=1,2,3, THEN RECOMP IS CALCULATED FROM
C                            WHITE'S EMPIRICAL CORRELATION
C                            BASED ON FFA DATA
C      DELTA  = BOUNDARY LAYER THICKNESS
C      SIGMF1 = FACTOR FOR SIGMA-I
C      SIGMF2 = FACTOR FOR SIGMA-E
C      NRCMP  = 0 EMPIRICAL RECOMPRESSION COEFFICIENTS
C                 WHITE RESPECTIVELY
C             = 1 RECOMPRESSION CRITERION AFTER PAGE,APPROXIMATED BY
C                 KORST
C             = 2 CORRECT PAGE CRITERION, CALCULATED ITERATIVELY
C                 (XPAGE = PRESCRIBED FRACTION OF TJML2 FOR DEFINING
C                 RECOMPRESSION BEGIN)
C             = 3 ONERA ANGULAR REATTACHMENT CRITERION
C             = 4 ONERA CRIT. MODIFIED FOR TWO STREAM REATACHMENT
C             = 5 AS 4, BUT SECOND ORDER CORRECTION FOR PHID
C             = 6 AS 4, BUT NONLINEAR TREATMENT (RECOMP=1. NECESSARY)
C      NSIGMA = 0 SIGMA AFTER KORST AND TRIPP
C             = 1 SIGMA AFTER CHANNAPRAGADA
C      NSHIFT = 0 ORIGIN SHIFT AFTER SOLIGNAC AND SIRIEUX  (NBLEED.GT.0)
C             = 1 ORIGIN SHIFT AFTER HILL (NBLEED.GT.0)
C             = 2 ORIGIN SHIFT SUPPRESSED
C      RDSIGN = STING DIAMETER FOR NOJET-CASE (PRATIO=0)
C      SEPHIS = ZUKOSKI CONSTANT
C      TROEI  = STAGNATION TEMPERATURE RATIO OF STREAMS, TOE/TOI.
C      X1,R1  = COORDINATES OF POINT WHERE SEPARATION OCCURS.
C               (R1'S ARE POSITIVE)
C      X2E,R2E= INITIAL COORDINATES OF THE AFTERBODY.
C
C
C      ***PRESSURE RATIO NOTATION***
C
C
C      PRIOI  = PII/POI,   PRIIE  = PII/PE,    PROIE  = POI/PE,
C      PRIIIE = PII/PIE,   POIEOI = POIE/POI,  PRIOIE = PIE/POIE,
C      PROIOE = POIE/POE,  PREOE  = PE/POE,    PROEOI = POE/POI,
C      PRBIE  = PB/PIE,    PRBOIE = PB/POIE,   PRBII  = PB/PII,
C      PRBOI  = PB/POI,    PRBE   = PB/PE,     PRIEE  = PIE/PE.
C
```

```
      COMMON PMB, CHARI, CHARE, P1, P2, P3
      COMMON  /DATAIO/  GCI,GAMMAI,EMSII,XII,RII,BETAII,
     1                  GCE,GAMMAE,EMSIE,XIE,RIE,BETAIE,PROIOE,
     2                  TROEI,PRIIE,RECOMP,A,EMNII,PRIOI,EMNIE,PRIOIE,
     3                  NPRINT,NCASI,NCASE,BLDRO,ENGRO,RE,EMNE,PREOE,
     4                  NPUNCH,PROEOI,PROIF,POIEOI,NSHAPE,NPTSE,PRIIIE,
     5                  NDEFLT,BLMTF,BLMTI
      COMMON /CM1/CDBT,XFIX,RFIX,NSEP,SEPRIS,XTEST,EEE,SEPP,DELTA
      COMMON /CM2/X2E,R2E
      COMMON /CM3/SIGMF1,SIGMF2,NRCMP,NSIGMA,NBLEED,XPAGE,NSHIFT,THRSLP
     1          ,RECMP1,RECMP2
      COMMON /ICROS/ICROSS,BPR
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1          P3(5), A(20)
      EMNMSF(EMS,GAMMA)=SQRT(((2.0*(EMS**2))/(GAMMA+1.0))/
     1                  (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))   )
      EMSMNF(EMN,GAMMA)=SQRT((0.5*(GAMMA+1.0)*(EMN**2))/
     1                  (1.0+0.5*(GAMMA-1.0)*(EMN**2)))
      PRMNF(EMN,GAMMA)=(1.0+((GAMMA-1.0)/2.0)*(EMN**2))**
     1                 (-GAMMA/(GAMMA-1.0))
      IF (NCASI.NE.0) GO TO 80
      GCE=53.35
      GAMMAE=1.4
      RECOMP=0.0
      NPUNCH=0
      NPRINT=-1
      BLDRO=0.0
      ENGRO=0.0
      SIGMF1=1.0
      SIGMF2=1.0
      NSHIFT=0
      NAMELIST/DATA/NPRINT,NSHAPE,X1E,R1E,X2E,R2E,BETD2E,EMNE,
     1              XII,RII,BETDII,GCI,GAMMAI,EMNII,TROEI,KPRESR
C      *********************************************************
C       INTERACTIVE INPUT OF DATA
C
      WRITE(5,71)
   71 FORMAT(5X,'ENTER INPUT OPTION CHOICE, 1=FILE   2=TERMINAL')
      READ(5,72) INOPT
   72 FORMAT (I1)
      WRITE(5,59)
   59 FORMAT(1H ,'ENTER NRCMP RECOMPRESSION CHOICE',/,5X,
     1'0= EMPIRICAL RECOMP COEFF AFTER ADDY OR WHITE',/,5X,
     2'1= KORST APPROXIMATION OF PAGE CRITERION',/,5X,
     3'2= CORRECT PAGE CRITERIA CALCULATED ITERATIVELY',/,5X,
     4'3= ONERA ANGULAR REATTACHMENT CRITERION',/,5X,
     5'4= ONERA CRITERIA MODIFIED FOR 2-STREAM REATTACH',/,5X,
     6'5= AS 4,SECOND ORDER CORRECTION FOR PHID',/,5X,
     7'6= AS 4,NONLINEAR TREATMENT (RECOMP=1,NEC.)')
       READ (5,13) NRCMP
       IF (NRCMP.NE.0) GO TO 7
       WRITE (5,5)
 5     FORMAT(1H ,'ENTER RECOMP')
       READ (5,6) RECOMP
 6     FORMAT(F6.4)
10     FORMAT(20A4)
11     FORMAT(4F10.4)
12     FORMAT(1H ,'XXXXX.XXXX')
13     FORMAT(I1)
14     FORMAT(1H ,'ENTER ALPHANUMERIC HEADING - 20A4')
 7     CONTINUE
       WRITE(5,14)
       READ(5,10)(A(I),I=1,20)
```

```
      WRITE(5,8)
 8    FORMAT(1H ,'ENTER NSHIFT')
      READ(5,9) NSHIFT
 9    FORMAT(I1)
      IF (INOPT.EQ.1) GO TO 70
C     ********INPUT EXTERNAL PARAMETERS*************************
15    FORMAT(1H ,'AFTERBODY SHAPE PARAMETERS:')
16    FORMAT(1H ,'   0 - CYLINDRICAL AFTERBODY')
17    FORMAT(1H ,'   1 - OGIVE BOATTAIL')
18    FORMAT(1H ,'   2 - PARABOLIC BOATTAIL')
19    FORMAT(1H ,'   3 - CONICAL BOATTAIL OR FLARE')
20    FORMAT(1H ,'ENTER AFTERBODY SHAPE PARAMETER - I1')
      WRITE(5,15)
      WRITE(5,16)
      WRITE(5,17)
      WRITE(5,18)
      WRITE(5,19)
      WRITE(5,20)
      READ(5,13)NSHAPE
21    FORMAT(1H ,'BODY AND NOZZLE DIMENSIONS ARE RELATIVE')
22    FORMAT(1H ,'THEY CAN BE INCHES, FEET, OR CALIBERS')
23    FORMAT(1H ,'"X" DIMENSIONS ARE POSITIVE AFT')
      WRITE(5,21)
      WRITE(5,22)
      WRITE(5,23)
24    FORMAT(1H ,'ENTER "X" AT BODY BASE')
      WRITE(5,24)
      WRITE(5,12)
      READ(5,11)X1E
25    FORMAT(1H ,'ENTER RADIUS AT BODY BASE')
      WRITE(5,25)
      WRITE(5,12)
      READ(5,11)R1E
      IF (NSHAPE.EQ.0) GO TO 49
26    FORMAT(1H ,'ENTER "X" AT START OF BOATTAIL')
      WRITE(5,26)
      WRITE(5,12)
      READ(5,11)X2E
27    FORMAT(1H ,'ENTER RADIUS AT START OF BOATTAIL')
      WRITE(5,27)
      WRITE(5,12)
      READ(5,11)R2E
28    FORMAT(1H ,'ENTER SLOPE AT START OF BOATTAIL - DEG')
      WRITE(5,28)
      WRITE(5,12)
      READ(5,11)BETD2E
29    FORMAT(1H ,'ENTER FREE STREAM MACH NUMBER')
49    WRITE(5,29)
      WRITE(5,12)
      READ(5,11)EMNE
C     ***********INPUT INTERNAL PARAMETERS*************************
30    FORMAT(1H ,'ENTER "X" AT END OF NOZZLE')
      WRITE(5,30)
      WRITE(5,12)
      READ(5,11)X1I
32    FORMAT(1H ,'ENTER NOZZLE EXIT RADIUS')
      WRITE(5,32)
      WRITE(5,12)
      READ(5,11)R1I
33    FORMAT(1H ,'ENTER NOZZLE EXIT ANGLE - DEG.')
      WRITE(5,33)
      WRITE(5,12)
      READ(5,11)BETD1I
```

```
34     FORMAT(1H ,'ENTER NOZZLE GAS CONSTANT - LBF/LBM R')
35     FORMAT(1H ,'      53.34 FOR AIR')
       WRITE(5,34)
       WRITE(5,35)
       WRITE(5,12)
       READ(5,11)GCI
36     FORMAT(1H ,'ENTER NOZZLE GAMMA - 1.4 FOR AIR')
       WRITE(5,36)
       WRITE(5,12)
       READ(5,11)GAMMAI
37     FORMAT(1H ,'ENTER NOZZLE EXIT MACH NUMBER')
       WRITE(5,37)
       WRITE(5,12)
       READ(5,11)EMN1I
38     FORMAT(1H ,'ENTER EXTERNAL TO INTERNAL STREAM STAGNATION')
39     FORMAT(1H ,'TEMPERATURE RATIO - TOE/TOI')
       WRITE(5,38)
       WRITE(5,39)
       WRITE(5,12)
       READ(5,11)TROEI
40     FORMAT(1H ,'ENTER NUMBER OF CASES - I1')
   70  WRITE(5,40)
       READ(5,13)NCASE
       IF (INOPT.EQ.1) READ(4,DATA)
       IF (INOPT.EQ.1) GO TO 79
41     FORMAT(1H ,' ENTER TYPE OF PRESSURE RATIO INPUT')
42     FORMAT(1H ,'    1 FOR INTERNAL STAGNATION/EXT STATIC PRESSURE')
43     FORMAT(1H ,'    0 FOR INTERNAL STATIC/EXTERNAL STATIC PRESSURE')
       WRITE(5,41)
       WRITE(5,42)
       WRITE(5,43)
       READ(5,13)KPRESR
44     FORMAT(1H ,'ENTER POJ/PF')
45     FORMAT(1H ,'ENTER PJ/PF')
C*****CALCULATION OF PROGRAM DATA.
   79 BETA1I= 0.0174532*BETD1I
      EMS1I = EMSMNF(EMN1I,GAMMAI)
      PR1OI = PRMNF(EMN1I,GAMMAI)
      D1I = 2.0*R1I
      D1E = 2.0*R1E
      X1ID1E = X1I/D1E
      EMSE = EMSMNF(EMNE,GAMMAE)
      PPEOE = PRMNF(EMNE,GAMMAE)
      RIE1 = R1I/R1E
      IF(NSHAPE.NE.0)  GO TO 56
C*****UNIFORM EXTERNAL FLOW WITHOUT AN AFTERBODY.
      RE = R1E
      EMN1E = EMNE
      EMS1E = EMSE
      PR1O1E = PREOE
      PRO1OE = 1.0
      GO TO 62
C*****AFTERBODY BEFORE THE EXTERNAL STREAM'S SEPARATION POINT.
   56 BETA2E=0.0174532*BETD2E
      CALL ABTS(GAMMAE,EMSE,X2E,R2E,BETA2E,X1E,R1E,NSHAPE,
     1          1,NPTSE,NERROR,CDBT)
C*****SET-UP DATA FOR EXTERNAL STREAM'S SEPARATION POINT.
      X1E=CHARE(1,1)
      R1F=CHARE(2,1)
      EMS1E = CHARE(3,1)
      EMN1E = EMNMSF(EMS1E,GAMMAE)
      BETA1E = CHARE(4,1)
      BETD1E = 57.2957795*BETA1E
```

```
      PRIOIE = PRMSF(EMNIE,GAMMAE)
      PROIOE=1.0
      RE = R2E
      D2E = 2.0*R2E
      X2ED2E = X2E/D2E
      X1ED2E = X1E/D2E
      DRIE2E = D1E/D2E
C*****RECOMPRESSION COEFFICIENT DETERMINATION.
62    IF(RECOMP.GT.1.0E-03)  GO TO 80
      IF(NSHAPE.NE.0)  GO TO 64
C*****FOR CYLINDRICAL AFTERBODIES.
      RECOMP = .483 + 1.086*RIE1 - 0.874*RIE1**2 + 0.303*RIE1**3
      GO TO 80
C*****FOR BOATTAILED AFTERBODIES.
  64  RATIO= (RII/RIE)/((30.0-BETD1I)/(20.0+BETD2E))
      SHETA= BETD2E+BETD1I
      EMM= -0.1875*SHETA+0.55
      IF (SHETA.LT.-8.) EMM=-0.575*SHETA-2.55
      IF (SHETA.GT.-4.) EMM=-0.0375*SHETA+1.15
      RECOMP= EMM*RATIO+0.5
C
  80  NCAS1 = NCAS1 + 1
C*****TRANSFER OR READ NEW CASE DATA.
C
       IF(KPRESR.GT.0)GO TO 82
       CALL BEEP(10,5)
       WRITE(5,45)
       WRITE(5,12)
       READ(5,11)PRATIO
       GO TO 88
  82   CALL BEEP(10,5)
       WRITE(5,44)
       WRITE(5,12)
       READ(5,11)PRATIO
C
  88  IF(KPRESR.NE.0)  GO TO 90
C*****FOR PII/PE (PRIIE) INPUT.
      PRIIE=PRATIO
      PROIE=PRIIE/PRIOI
      GO TO 92
C*****FOR POI/PE (PROIE) INPUT.
  90  PROIE=PRATIO
      PRIIE = PROIE*PRIOI
C*****CALCULATE VARIOUS PRESSURE RATIOS FROM NEW CASE DATA.
  92  PROEOI=PRIOI/(PREOE*PRIIE)
      POIEOI=PROEOI*PROIOE
      PRIIIE=PRIOI/(POIEOI*PRIOIE)
      PRIEE=PRIOIE*PROIOE/PREOE
      WRITE(5,46)
  46  FORMAT(1H,'ENTER BOUNDRY LAYER MOMENTUM THICKNESS AT BODY BASE')
      WRITE(5,12)
      READ(5,11)BLMTE
      WRITE(5,47)
  47  FORMAT(1H,'ENTER BOUNDRY LAYER MOMENTUM THICKNESS AT NOZZLE EXIT')
      WRITE(5,12)
      READ(5,11)BLMTI
C*****PRINT CASE DATA.
      WRITE  (3,94)          (A(I),I=1,20), NRCMP,NCAS1
  94  FORMAT(1H1,5X,20A4,2X,' NRCMP=',I1,9X,15HPROBLEM NUMBER I3,//)
C
      IF(NSHAPE.EQ.0)  GO TO 180
      GO TO (100,120,140),NSHAPE
C
```

```
 100   WRITE (3,110)
 110   FORMAT (29X,21H ***OGIVE BOATTAIL*** //)
       GO TO 160
C
 120   WRITE (3,130)
 130   FORMAT (27X,25H ***PARABOLIC BOATTAIL*** //)
       GO TO 160
C
 140   WRITE (3,150)
 150   FORMAT (28X,23H ***CONICAL BOATTAIL*** //)
C
 160   WRITE (3,170)            X2E, R2E, BETD2E, EMNE, CDBT, PR1EE
 170   FORMAT (15X,6H X2E= ,F6.3,7X,6H R2E= ,F6.3,9X,14H BETA2E(DEG)= ,
      1        F7.3,/,15X,8H EMNE = ,F7.4, 4X,8H CDBT = ,F6.3,
      2        7X,9H P1E/PE = F7.5,//)
C
 180   WRITE(3,190) NCAS1,GAMMAI,GCI,X1I,R1I,BETD1I,EMN1I,EMS1I,PR1OI,
      1                  GAMMAE,GCE,X1E,R1E,BETD1E,EMN1E,EMS1E,PR1O1E
 190   FORMAT(10X,41H ****TWO-STREAM BASE PRESSURE PROGRAM**** ,5X,
      1  10H PROB. NO. I4,/,4X,23H ******INPUT DATA******,/,
      2  28X,22H ***INTERNAL STREAM***, //,
      3  15X,9H GAMMAI= F5.3, 5X,16H GAS CONSTANT = F7.2,11H LB-FT/LB-R,
      4  / ,15X,6H X1I= F6.3,7X,6H R1I= F6.3,9X,14H BETA1I(DEG)= F7.3,/,
      5  15X,8H EMN1I =F7.4,4X,8H EMS1I =F7.4,6X,10H P1I/POI =F7.5,
      6  /,28X,22H ***EXTERNAL STREAM***, /,
      7  15X,9H GAMMAE= F5.3, 5X,16H GAS CONSTANT = F7.2,11H LB-FT/LB-R,
      8  / ,15X,6H X1E= F6.3,7X,6H R1E= F6.3,9X,14H BETA1E(DEG)= F7.3,/,
      9  15X,8H EMN1E =F7.4,4X,8H EMS1E =F7.4,6X,11H P1E/PO1E =F7.5/)
C
       WRITE (3,200)           PR1IE, TROEI, RLDRO, ENGRO,BLMTE,BLMTI
 200   FORMAT(21X,36H *****BASE PRESSURE CASE DATA******, /,
      1  15X,11H P1I/PE  = F9.4,17X,11H TOE/TOI = F8.5,/,
      2  15X, 9H RLDRO = E12.5, 16X, 9H ENGRO = E12.5,/
      3  15X, 9H BLMTE = E12.5, 16X, 9H BLMTI = E12.5,/)
C
       WRITE (3,210)           RECUMP
 210   FORMAT( 18X, 32H ***RECOMPRESSION COEFFICIENT =  F5.3, 3H***, /,
      1 15X,51H ***************************************************    /)
C
       RETURN
       STOP
       END
C      ***********************************************************
C
       SUBROUTINE ACPBS(GAMMA,EMS1,PRATIO,XCO,RCO,BETAO,RLMT,NCALC,NPTS,
      1                 NPRINT,NFLOW,NPPTS,BPTS,NSHAPE)
C
C*****AXISYMMETRIC CONSTANT PRESSURE BOUNDARY SUBPROGRAM (ACPBS).
C
C      INTERNAL FLOW (NFLOW=1) --- UNIFORM OR CONICAL SUPERSONIC FLOW.
C                                  CALCULATIONS ARE FOR THE *LOWER-HALF*
C                                  OF THE FLOW FIELD.
C
C      EXTERNAL FLOW (NFLOW=2) --- INITIALLY UNIFORM SUPERSONIC FLOW.
C                                  CALCULATIONS ARE FOR THE *UPPER-HALF*
C                                  OF THE FLOW FIELD.
C
C      NOTE --- INPUT AND OUTPUT DATA ARE FOR THE *UPPER-HALF* OF FLOW
C               FIELD. THE ADJUSTMENT OF THESE DATA FOR THE CALCULATIONS
C               IS MADE INTERNALLY.
C
C      SUBPROGRAM REQUIRES---OUTPUT,PMSHR,UFLOC,CNFLOC,FPS,APS,CPHS,
C                            MCDATA,OUTHDY,TEST.
```

```
C
C      ***VARIABLES***
C
C      GAMMA = RATIO OF THE SPECIFIC HEATS.
C      EMS1  = INITIAL MACH STAR AT POINT 1.
C      PRATIO= EXPANSION PRESSURE RATIO (P/PO).
C      XCO   = LONGITUDINAL COORDINATE WHERE EXPANSION IS CENTERED.
C      RCO   = RADIAL COORDINATE WHERE EXPANSION IS CENTERED, POSTIVE.
C      BETAO = FLOW ANGLE, RADIANS, AT (XCO,RCO) FOR INTERNAL FLOW, POS.
C      RLMT  = LIMITING VALUE OF THE RADIUS FOR TERMINATING CALCULATIONS.
C              (MAX. R FOR INTERNAL FLOW AND MIN. R FOR EXTERNAL FLOW)
C      NCALC = CURRENT CALCULATION NUMBER
C            = 1, THE INITIAL CHARACTERISTIC DATA IS CALCULATED.
C         .GT.1, INITIAL CHAR. DATA TAKEN FROM ONE OF THE STORED ARRAYS.
C      NPTS  = NO. OF POINTS OR INCREMENTS ON INITIAL II-CHARACTERISTIC.
C      NPRINT= -1 OR 0, C.P.B. DATA NOT PRINTED.
C              +1, C.P.B. DATA PRINTED.
C      NFLOW = 1, INTERNAL FLOW.
C              2, EXTERNAL FLOW.
C      NBPTS = NUMBER OF BOUNDARY POINTS CALCULATED.
C      BPTS  = BOUNDARY POINT DATA ARRAY, N=1,LIMIT.
C      PMB, CHARI, CHARE = ARRAYS FOR METHOD OF CHARACTERISTICS.
C
C      ***OUTPUT DATA (IN ORDER)***
C
C      INPUT DATA TO ACPBS
C      PRATIO= EXPANSION PRESSURE RATIO (P/PO).
C      EMN2  = MACH NUMBER ALONG BOUNDARY AFTER EXPANSION.
C      EMS2  = MACH STAR ALONG BOUNDARY AFTER EXPANSION.
C      X     = LONGITUDINAL COORDINATE OF BOUNDARY POINT.
C      R     = RADIAL COORDINATE OF BOUNDARY POINT.
C      THETA = LOCAL FLOW ANGLE AT BOUNDARY POINT (IN DEGREES).
C
C
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1   P3(5), BPTS(5,30), SIGN(5)
      COMMON PMB, CHARI, CHARE, P1, P2, P3
C*****INPUT DATA, SOME OUTPUT DATA, AND COLUMN HEADINGS ARE PRINTED.
      CALL OUTPUT(GAMMA,EMS1,PRATIO,BETAO,NPRINT,NFLOW)
C*****SET INPUT DATA FOR THE FLOW FIELD CALCULATIONS.
      GO TO (2,4), NFLOW
    2 RC=-RCO
      XC=XCO
      BETA=-BETAO
      GO TO 6
    4 RC=RCO
      XC=XCO
      BETA=BETAO
    6 CONTINUE
C*****SET SIGNS FOR CONVERTING OUTPUT DATA TO THE *UPPER-HALF*
C     OF THE FLOW FIELD.
C
      DO 30 N=1,5
      GO TO (10,20), NFLOW
   10 SIGN(N)=(-1.0)**(N+1)
      GO TO 30
   20 SIGN(N)=1.0
   30 CONTINUE
C*****THE MAXIMUM NUMBER OF FAMILY I CHARACTERISTICS FOR WHICH
C     CALCULATIONS ARE MADE IS SPECIFIED HERE (MAX. LIMIT IS 30).
C
      LIMIT=30
C*****THE INITIAL II-CHAR. IS NOW SUBDIVIDED AND THE INITIAL CHAR.
```

```
C      DATA CALCULATED (MAX. NO. OF INCREMENTS = 29).
C
       IF(NCALC-1) 50,50,110
    50 GO TO (60,90), NFLOW
C*****FOR INTERNAL FLOW FIELD.
    60 IF(ABS (BETA)-1.0E-4) 70,70,80
C*****FOR UNIFORM FLOW.
    70 CALL UFLOC(GAMMA,EPS1,XC,RC,NPTS,CHARI,NFLOW)
       GO TO 110
C*****FOR CONICAL FLOW.
    80 CALL CNFLOC(GAMMA,EPS1,BETA,XC,RC,NPTS)
       GO TO 110
C*****FOR EXTERNAL FLOW FIELD.
    90 IF(NSHAPE) 96,96,100
C*****FOR UNIFORM EXTERNAL FLOW WITHOUT A BOATTAIL.
    96 CALL UFLOC(GAMMA,EPS1,XC,RC,LIMIT-1,CHARE,NFLOW)
       NPTS=LIMIT
       GO TO 110
C*****FOR UNIFORM EXTERNAL FLOW WITH A BOATTAIL.
   100 LIMIT=NPTS
C*****THE PRANDTL-MEYER EXPANSION AT (XC,RC) IS NOW SUBDIVIDED.
   110 CALL  PMSBR(GAMMA,EPS1,PRATIO,BETA,XC,RC,K)
C*****K1 IS NUMBER OF FAMILY II CHAR. FOR SUBDIVIDED EXPANSION.
       K1 = K + 1
C*****STORAGE OF INITIAL BOUNDARY POINT DATA.
       NBPTS=1
       DO 120 M=1,4
   120 BPTS(M,1)=SIGN(M)*PMB(K1,M,1)
C*****THE INITIAL BOUNDARY POINT DATA IS PRINTED.
       CALL OUTBDY(1,NPRINT,BPTS)
C*****THE FLOW FIELD CALCULATIONS ARE NOW MADE ALONG FAMILY I CHARS.
C      STARTING FROM THE INPUT POINTS ON THE SUBDIVIDED INITIAL
C      FAMILY II CHARACTERISTICS TO THE BOUNDARY.  THIS SEQUENCE IS
C      NOT APPLICABLE FOR THE FIRST AND SUBSEQUENT AXIS POINTS.
C
       DO 180 N=2,NPTS
C*****LOAD INITIAL FAMILY II CHARACTERISTIC DATA.
       DO 150 M=1,4
       GO TO (130,140), NFLOW
   130 PMB(1,M,2)=CHARI(M,N)
       GO TO 150
   140 PMB(1,M,2)=CHARE(M,N)
   150 CONTINUE
C*****CALCULATIONS ARE FOR THE CURRENT N-TH POINT ON THE INITIAL
C      FAMILY II CHARACTERISTIC.
C
       DO 160 L=1,K
C*****CALCULATIONS ARE FOR THE CURRENT L-TH EXPANSION INCREMENT.
C*****LOAD DATA/ FIELD POINT CALCULATION/ STORE DATA.
       CALL MCDATA(1,L,L+1,L3,KPTS)
       CALL FPS(GAMMA, P1, P2, P3, NERROR)
       IF(NERROR) 270,154,154
   154 CALL MCDATA(2,L1,L2,L+1,KPTS)
   160 CONTINUE
C*****ALL FIELD POINTS ON N-TH FAMILY I CHAR. HAVE BEEN CALCULATED.
C*****LOAD DATA/ BOUNDARY POINT CALCULATION/ STORE DATA.
       CALL MCDATA(1,K+1,K+1,L3,KPTS)
       CALL CPMS(GAMMA, P1, P2, P3, NERROR)
       IF(NERROR) 270,164,164
   164 CALL MCDATA(2,L1,L2,K+2,KPTS)
       NBPTS=NBPTS+1
       DO 170 M=1,4
   170 BPTS(M,N)=SIGN(M)*P3(M)
```

```
C*****CHARACTERISTICS DATA SHIFT.
      CALL MCDATA(3,L1,L2,L3,K+2)
C*****THE CURRENT BOUNDARY POINT DATA IS NOW PRINTED.
      CALL OUTBDY(N,NPRINT,BPTS)
      CALL TEST(RLMT,NSTMT,NFLOW,N,BPTS)
      GO TO (180,260), NSTMT
C*****ADVANCE INDEX FOR NEXT INPUT POINT ON INITIAL CHARACTERISTIC.
  180 K=K+1
      GO TO (190,260), NFLOW
C*****THIS SEQUENCE APPLIES ONLY TO THE INTERNAL FLOW WHERE THE AXIS
C     POINTS ARE CONSIDERED.
C*****THE NUMBER OF POINTS TO BE CALCULATED ALONG EACH FAMILY I CHAR.
C     IS NOW CONSTANT AND GIVEN BY K1.
C
  190 K1=K+1
      KPTS=K1+1
      N=NPTS
C*****THE ELEMENTS IN THE N-TH COLUMN OF THE PMB ARRAY ARE SHIFTED
C     DOWN ONE ROW TO SET-UP THE CALCULATION SEQUENCE.
C
      DO 210 L=1,K1
      L1 = K1-L+1
      DO 200 M=1,4
  200 PMB(L1+1,M,1)=PMB(L1,M,1)
  210 CONTINUE
C*****THE CALCULATIONS ARE NOW MADE ALONG THE (N+1)-TH FAMILY I CHAR.
  220 N=N+1
C*****LOAD DATA/ AXIS POINT CALCULATION/ STORE DATA.
      CALL MCDATA(1,1,2,L3,KPTS)
      CALL APS (GAMMA, P2, P3, NERROR)
      IF(NERROR) 270,224,224
  224 CALL MCDATA(2,L1,L2,1,KPTS)
C*****CALCULATION OF REMAINDER OF FIELD POINTS ON N-TH FAMILY I CHAR.
      DO 230 L=2,K1
C*****LOAD DATA/ FIELD POINT CALCULATION/ STORE DATA.
      CALL MCDATA(1,L-1,L+1,L3,KPTS)
      CALL FPS(GAMMA, P1, P2, P3, NERROR)
      IF(NERROR) 270,228,228
  228 CALL MCDATA(2,L1,L2,L,KPTS)
  230 CONTINUE
C*****LOAD DATA/ BOUNDARY POINT CALCULATION/ STORE DATA.
      CALL MCDATA(1,K1,K1+1,L3,KPTS)
      CALL CPBS(GAMMA, P1, P2, P3, NERROR)
      IF(NERROR) 270,234,234
  234 CALL MCDATA(2,L1,L2,K1+1,KPTS)
      NBPTS=NBPTS+1
      DO 240 M=1,4
  240 BPTS(M,N)=SIGN(M)*P3(M)
C*****CHARACTERISTICS DATA SHIFT.
      CALL MCDATA(3,L1,L2,L3,KPTS)
C*****THE CURRENT BOUNDARY POINT DATA IS PRINTED.
      CALL OUTBDY(N,NPRINT,BPTS)
      CALL TEST(RLMT,NSTMT,NFLOW,N,BPTS)
      GO TO (250,260), NSTMT
C*****COMPARISON WITH LIMITING NUMBER OF FLOW FIELD CALCULATIONS.
  250 IF(N-LIMIT) 220,260,260
C*****IF NEGATIVE, CONTINUE CALCULATIONS.
C*****IF ZERO OR POSTIVE, RETURN TO MASTER.
  260 CONTINUE
  270 RETURN
      END
      SUBROUTINE CROSS(GAMMAI,NPTI,LIMITI,GAMMAE,NPTE,LIMITE,NIC,NEC,
     1                 NSTOP,IJMLI,TJMLE,PRSHOP,NPRINT)
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```
C
C*****THIS SUBROUTINE CALCULATES THE IMPINGEMENT POINT OF THE
C     SUPERSONIC INTERNAL (I) AND EXTERNAL (E) STREAMS.
C
C     SUBROUTINE REQUIRES---PRSHK,SLIP.
C
C     ***VARIABLES***
C
C     GAMMAI = RATIO OF THE SPECIFIC HEATS FOR THE INTERNAL STREAM.
C     BPTI   = INTERNAL STREAM BOUNDARY DATA.
C     LIMITI = NUMBER OF INTERNAL STREAM BOUNDARY POINTS.
C     GAMMAE = RATIO OF THE SPECIFIC HEATS FOR THE EXTERNAL STREAM.
C     BPTE   = EXTERNAL STREAM BOUNDARY DATA.
C     LIMITE = NUMBER OF EXTERNAL STREAM BOUNDARY POINTS.
C     NIC    = LOCATION NO. OF INTERNAL STREAM IMPINGEMENT POINT.
C     NEC    = LOCATION NO. OF EXTERNAL STREAM IMPINGEMENT POINT.
C     NSTOP  = 0, SOLUTION FOUND.
C            = 1, NO IMPINGEMENT.
C            = 2, NO SHOCK SOLUTION.
C            = 3, IMPINGEMENT BEFORE SEPARATION.
C     TJMLI  = INTERNAL TURBULENT JET MIXING LENGTH.
C     TJMLE  = EXTERNAL TURBULENT JET MIXING LENGTH.
C     F1,F2 = ABSCISSA FOR AXISYMMETRIC CORRECTION TERMS USED IN ONERA
C              ANGULAR REATACHMENT CRITERION
C     PRSHOK = STATIC PRESS. RATIO (RISE) ACROSS OBLIQUE SHOCK SYSTEM.
C     NPRINT = SEE SUBROUTINE *INOUT*.
C
C     BPTI(M,N) AND BPTE(M,N) ARE BOUNDARY POINT DATA ARRAYS WHERE
C              M=1,4  AND INDICATES VARIABLE AS IN PMB ARRAY.
C              N=1,LIMITI OR LIMITE  INDICATES THE BOUNDARY POINT.
C
C
      DIMENSION XI(30),RI(30),XE(30),RE(30),BPTI(5,30),BPTE(5,30)
      COMMON /ANGLES/THETA1,THETA2,THETAS,F1,F2
      EMNMSF(EMS,GAMMA)=SQRT(((2.0*(EMS**2))/(GAMMA+1.))/
     1                 (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2)))
C*****LOADING OF CONSTANT-PRESSURE BOUNDARY POINT DATA.
      DO 10 N=1,LIMITI
      XI(N)=BPTI(1,N)
   10 RI(N) = BPTI(2,N)
      DO 20 N=1,LIMITE
      XE(N) = BPTE(1,N)
   20 RE(N) = BPTE(2,N)
C*****SET INITIAL VALUES.
      NSTOP=1
      PRSHOK=0.0
      NIMAX=LIMITI-1
      NEMAX=LIMITE-1
C*****CHECK FOR IMPINGEMENT UPSTREAM OF THE SEPARATION POINTS.
C*****FOR THE INTERNAL STREAM.
      SE=0.0
      NE=1
      DO 30 NI=1,NIMAX
      SI = (RI(NI+1) - RI(NI))/(XI(NI+1) - XI(NI))
      IF(ABS(SE-SI) .LT. 1.0E-05)  GO TO 30
      XIMP = (RI(NI) - RE(NE) + SE*XE(NE) - SI*XI(NI))/(SE - SI)
      IF((XIMP.GE.XI(NI)).AND.(XIMP.LE.XI(NI+1)).AND.
     1   (XIMP.LE.XE(NE)))  GO TO 50
   30 CONTINUE
C*****FOR THE EXTERNAL STREAM.
      SI=0.0
      NI=1
      DO 40 NE=1,NEMAX
```

```
      SE = (RE(NE+1) - RE(NE))/(XE(NE+1) - XE(NE))
      IF(ABS(SE-SI) .LT. 1.0E-05)  GO TO 40
      XIMP = (RI(NI) - RE(NE) + SE*XE(NE) - SI*XI(NI))/(SE - SI)
      IF((XIMP.GE.XE(NE)).AND.(XIMP.LE.XE(NE+1)).AND.
     1   (XIMP.LE.XI(NI)))  GO TO 70
   40 CONTINUE
      GO TO 100
C*****IF IMPINGEMENT OCCURS.
   50 RIMP = (SE*SI*(XE(NE)-XI(NI)) + SE*RI(NI) - SI*RE(NE))/(SE-SI)
C
      WRITE (3,60)             XIMP,RIMP
   60 FORMAT( 15X, 48H ******IMPINGEMENT OF THE INTERNAL STREAM OCCURS /
     1 21X, 47H BEFORE SEPARATION OF THE EXTERNAL STREAM****** , /,
     2 16X, 27H IMPINGEMENT OCCURS AT X = F10.6, 5X, 9H AND R = F10.6 /)
      GO TO 90
C
   70 RIMP = (SE*SI*(XE(NE)-XI(NI)) + SE*RI(NI) - SI*RE(NE))/(SE-SI)
C
      WRITE  (3,80)            XIMP,RIMP
   80 FORMAT( 15X, 48H ******IMPINGEMENT OF THE EXTERNAL STREAM OCCURS /
     1 21X, 47H BEFORE SEPARATION OF THE INTERNAL STREAM****** , /,
     2 16X, 27H IMPINGEMENT OCCURS AT X = F10.6, 5X, 9H AND R = F10.6 /)
C
   90 NSTOP=3
      GO TO 230
C*****CALCULATION OF CONSTANT-PRESSURE BOUNDARIES IMPINGEMENT POINT.
  100 DO 120 NI=1,NIMAX
      SI = (RI(NI+1) - RI(NI))/(XI(NI+1) - XI(NI))
      DO 110 NE=1,NEMAX
      SE = (RE(NE+1) - RE(NE))/(XE(NE+1) - XE(NE))
      IF(ABS(SE-SI) .LT. 1.0E-05)  GO TO 110
      XIMP = (RI(NI) - RE(NE) + SE*XE(NE) - SI*XI(NI))/(SE - SI)
      IF((XIMP.GE.XI(NI)) .AND. (XIMP.LE.XI(NI+1)) .AND.
     1   (XIMP.GE.XE(NE)) .AND. (XIMP.LE.XE(NE+1)))  GO TO 140
  110 CONTINUE
  120 CONTINUE
C*****FOR NO IMPINGEMENT OF THE STREAMS.
      WRITE (3,130)
  130 FORMAT(16X, 41H ***IMPINGEMENT DOES NOT OCCUR WITHIN THE  ,/,
     1   19X, 44H RANGE OF CONSTANT-PRESSURE BOUNDARY DATA***   /)
      NSTOP=2
      GO TO 230
C*****FOR IMPINGEMENT OF THE STREAMS.
  140 RIMP = (SE*SI*(XE(NE)-XI(NI)) + SE*RI(NI) - SI*RE(NE))/(SE-SI)
      NIC=NI+1
      NEC=NE+1
C*****INTERPOLATION FOR THE FLOW VARIABLES AT THE IMPINGEMENT POINT.
      DO 150 M=3,4
      BPTI(M,NIC) = BPTI(M,NIC-1) + ((XIMP - XI(NIC-1))/
     1              (XI(NIC) - XI(NIC-1)))*(BPTI(M,NIC) - BPTI(M,NIC-1))
  150 BPTE(M,NEC) = BPTE(M,NEC-1) + ((XIMP - XE(NEC-1))/
     1             (XE(NEC) - XE(NEC-1)))*(BPTE(M,NEC) - BPTE(M,NEC-1))
C*****STORE COORDINATES OF THE IMPINGEMENT POINT.
      BPTI(1,NIC) = XIMP
      BPTI(2,NIC) = RIMP
      BPTE(1,NEC)= XIMP
      BPTE(2,NEC) = RIMP
      THETA1= BPTI(4,NIC)
      THETA2= BPTE(4,NEC)
C**CALCULATION OF THE MIXING LENGTHS AND OF F FOR AXISYM. ONERA CRIT.
      TJMLI=0.0
      F1=0.0
      DO 160 M=2,NIC
```

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      DS=SQRT((BPTI(1,N)-BPTI(1,N-1))**2+(BPTI(2,N)-BPTI(2,N-1))**2)
      TJMLI=TJMLI+DS
 160  F1=F1+(BPTI(2,N)+BPTI(2,N-1))*0.5*DS
      F1=F1/(TJMLI*RIMP)
      F2=0.0
      TJMLE=0.0
      DO 170 N=2,NEC
      DS=SQRT((BPTE(1,N)-BPTE(1,N-1))**2+(BPTE(2,N)-BPTE(2,N-1))**2)
      TJMLE=TJMLE+DS
 170  F2=F2+(BPTE(2,N)+BPTE(2,N-1))*0.5*DS
      F2=F2/(TJMLE*RIMP)
C*****OUTPUT IMPINGEMENT POINT DATA.
      EMNI = EMNMSF(BPTI(3,NIC),GAMMAI)
      THETDI = 57.2957795*BPTI(4,NIC)
      EMNE = EMNMSF(BPTE(3,NEC),GAMMAE)
      THETDE = 57.2957795*BPTE(4,NEC)
      IF(NPRINT.LT.0) GO TO 200
C
      WRITE (3,180)
 180  FORMAT( 1H1 )
C
      WRITE (3,190)            XIMP,RIMP,EMNI,THETDI,TJMLI,
     1                         XIMP,RIMP,EMNE,THETDE,TJMLE
 190  FORMAT(//,18X,42H***AT INTERNAL STREAM IMPINGEMENT POINT*** ,//,
     1 5X, 5H X = F10.6, 5X, 5H R = F10.6, 5X, 12H MACH NO. = F10.6,//,
     2 5X, 15H THETA(DEG.) = F10.6, 5X, 17H MIXING LENGTH = F10.6,//,
     3 18X,  43H ***AT EXTERNAL STREAM IMPINGEMENT POINT*** ,//,
     4 5X, 5H X = F10.6, 5X, 5H R = F10.6, 5X, 12H MACH NO. = F10.6,//,
     5 5X, 15H THETA(DEG.) = F10.6, 5X, 17H MIXING LENGTH = F10.6,//)
C
C*****CALCULATION OF THE RECOMPRESSION SHOCK SYSTEM.
C*****CALCULATION OF THE SLIPLINE ANGLE.
 200  CALL SLIP(BPTI(3,NIC),BPTI(4,NIC),GAMMAI,
     1           BPTE(3,NEC),BPTE(4,NEC),GAMMAE,
     2           THETAS,NSTOP)
C*****DOES THE SOLUTION FOR THE SLIPLINE ANGLE EXIST.
      GO TO (210,230,230), NSTOP
C*****CALCULATION OF THE STATIC PRESSURE RATIO ACROSS THE SHOCK SYSTEM.
C     (NOTE  PRSHOKI=PRSHOKE=PRSHOK.)
C
 210  DELTAI = (BPTI(4,NIC) - THETAS)
      PRSHOK = PRSHK(BPTI(3,NIC),DELTAI,GAMMAI)
      THETAS = 57.2957795*THETAS
      IF(NPRINT.LT.0) GO TO 230
C*****OUTPUT OF SHOCK SYSTEM DATA.
C
      WRITE (3,220)            THETAS,PRSHOK
 220  FORMAT(15X, 48H ***OBLIQUE SHOCK SYSTEM AT IMPINGEMENT POINT***//,
     1        5X, 23H SLIPLINE ANGLE(DEG.) = F10.6,
     2        5X, 24H STATIC PRESSURE RATIO = F10.6,//)
C
 230  RETURN
      END
      SUBROUTINE TJMIX(GAMMA1,GC1,EMS1,TRRO1,TJML1,
     1                 GAMMA2,GC2,EMS2,TRRO2,TJML2,
     2                 RN1,EMSN1,BETAN1,RIMP,PRSHOK,
     3                 PRO21,TRO21,RECOMP,BLDR,ENGR,BLMT1,BLMT2,ITC)
C
C*****THIS SUBROUTINE CALCULATES THE DIMENSIONLESS BLEED AND
C     ENERGY RATIOS FOR THE TWO-STREAM INTERACTION PROBLEM.
C
C     SUBROUTINE REQUIRES---TEGRAL.
C
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C     ***VARIABLES***
C
C     FOR EITHER STREAM 1 OR 2
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     GC     = GAS CONSTANT---(LBF-FT/LBM-R).
C     EMS    = MACH STAR AT IMPINGEMENT POINT.
C     THETA  = FLOW ANGLE AT IMPINGEMENT POINT (IN RADIANS).
C     TRBO   = BASE TO FREE-STREAM STAGNATION TEMPERATURE RATIO.
C     TJML   = TURBULENT JET MIXING LENGTH.
C     F      = ABSCISSA FOR AXISYMMETRIC CORRECTION TERMS IN ONERA AN'
C                ANGULAR REATTACHMENT CRITERION
C
C     RN1    = NOZZLE EXIT RADIUS OF STREAM 1 (INTERNAL).
C     EMSN1  = NOZZLE EXIT MACH STAR OF STREAM 1.
C     BETAN1 = NOZZLE EXIT FLOW ANGLE AT RN1 (IN RADIANS).
C     RIMP   = RADIAL COORDINATE OF IMPINGEMENT POINT.
C     PRSHOK = STATIC PRESSURE RATIO (RISE) OF OBLIQUE SHOCK SYSTEM.
C
C     PPO21  = STAGNATION PRESSURE RATIO, PO2/PO1.
C     TRO21  = RATIO OF STAGNATION TEMPERATURES OF THE TWO STREAMS.
C     RECOMP = RECOMPRESSION COEFFICIENT.
C
C     BLDR   = MASS BLEED RATIO REFERENCED TO FLOW OF STREAM 1,
C              (G BLEED)/(G NOZZLE1).
C     ENGP   = ENERGY BLEED RATIO, (OMEGAB)/((G NOZZLE1)*CP1*TO1),
C              WHERE OMEGAB IS REFERENCED TO T=0.
C
      COMMON/ANGLES/THETA1,THETA2,THETAS,F1,F2
      COMMON/CW3/SIGMF1,SIGMF2,NRCMP,NSIGMA,NBLEED,XPAGE,NSHIFT,THRSLP,
     1           RECMP1,RECMP2
C
      CR2MSF(EMS,GAMMA) = ((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2)
      EMNMSF(EMS,GAMMA)=SORT  (((2.0*(EMS**2))/(GAMMA+1.0))/
     1                  (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))  )
      EMSMNF(EMN,GAMMA) =EMN*SORT(0.5*(GAMMA+1.)/(1.+0.5*(GAMMA-1.)*
     1EMN**2))
      EMSPRF(PR,GAMMA)=SORT  (((GAMMA+1.0)/(GAMMA-1.0))*
     1                 (1.0-PR**((GAMMA-1.0)/GAMMA)))
      WTFLMS (EMS,GAMMA)=SORT  (2.0*GAMMA/(GAMMA+1.0))*
     1                   (EMS/(1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2)))
      PRMSF(EMS,GAMMA)=(1.0-((GAMMA-1.0)/(GAMMA+1.0))*EMS**2)**
     1                 (GAMMA/(GAMMA-1.0))
      PHIDF(CNR,TRBO) = CNR*(0.5*CNR*(1.0-TRBO) +
     1                  SORT  ((CNR**2)*((0.5*(1.0-TRBO))**2)+TRBO))
C*****PRANDTL-MEYER-FUNCTION
      OMEGAF(EMN,GAMMA)=SORT((GAMMA+1.)/(GAMMA-1.))*ATAN(SORT((GAMMA-1.)
     1/(GAMMA+1.)*(EMN**2-1.)))-ACOS(1./EMN)
C*******PAGE CRITERION,APPROXIMATED BY KORST
      XKAPKO(EMN) = 0.02333*EMN+0.66333
C*****ORIGINAL PAGE CRITERION
      XKAPPA(PHID) = 0.5*(1.-COS(3.14159*(PHID-0.01)))
C*****ONERA ANGULAR CRITERION
C     REATTACHMENT ANGLE FOR CO=0 IN PLANE FLOW
C     PSIO(EMN) = 0.044215+0.17194*EMN-0.017952*EMN**2
      PSIO(EMN,PHIJ,GAMMA)=OMEGAF(EMN,GAMMA)-OMEGAF(EMN*SORT(1.-PHIJ**2)
     1,GAMMA)
C     CHANGE OF PSIO WITH CO
      PSIPHD(EMN,PHIJ,GAMMA,TRBO)=SORT(EMN**2*(1.-PHIJ**2/(TRBO+(1.-TRBO
     1)*PHIJ))-1.)/(1.+0.5*(GAMMA-1.)*EMN**2*(1.-PHIJ**2/(TRBO+(1.-TRBO)
     2*PHIJ))))*PHIJ/SORT((1.-PHIJ)*(TRBO+PHIJ)*(1.-PHIJ**2/(TRBO+(1.-
     3TRBO)*PHIJ))))*(TRBO+(1.-TRBO)*PHIJ/2.)/(TRBO+(1.-TRBO)*PHIJ)**1.5
      PHICO(PHIJ,ETAJ,CSOO,TRBO)=(TRBO+(1.-TRBO)*PHIJ-PHIJ**2*CSOO)/((1.-
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```
     2CSQD)*0.56419*EXP(-ETAJ**2)/PHIJ
C     FACTOR FOR SECOND ORDER CHANGE OF PHIP WITH CO
      P2COSF(PHIJ,ETAJ,CSQD,TRHO)=((TRHO+             PHIJ**2*CSQD)*
     10.56419*EXP(-ETAJ**2)+2.*(TRHO+(1.-TRHO)*PHIJ-PHIJ**2*CSQD)*ETAJ*
     2PHIJ)/PHIJ**2/(1.-CSQD)
C     CORRECTION FOR AXIALLY SYMMETRIC FLOW
      DPSIAX(ARG) = 0.047124-0.061087*(ARG**2-1)/(ARG**2+1)
      ARG(F) = EXP(F*5.4-4.4)
C     CORRECTION FOR MORE EXACT ORIGIN SHIFT
      CORUS(EMN)=2.9088-1.054*EMN+0.15512*EMN**2
C*****BLEED'S CORRECTION FOR LIMITING ANGLES                        LIMI
      EPSILF(EMN)=0.293375-0.177335*EMN+0.0413215*EMN**2-0.00311301*
     1EMN**3
C
      EPS=1.E-3
      IF (NRCMP.LT.3) GOTO 6
      PROD1=1.
      THETES=THETAS /57.2957795
      PROD2=1.
C*****DTARB ACCOUNTS FOR A CORRECTION OF REATTACHMENT ANGLES
C     DUE TO THE CONFLUENCE PROBLEM OF TWO SHEAR LAYERS
      DTARB=0.
C*****EPSIL ACCOUNTS FOR ONERA LIMITING ANGLES IN CORRESPONDENCE TO
C                           THOSE OF KORST
      EPSIL1=EPSILF(EMNMSF(EMS1,GAMMA1))
      EPSIL2=EPSILF(EMNMSF(EMS2,GAMMA2))
      ITMUST=1
      NTYPE=1
      NJUMP=NRCMP-3
      DT=-0.02
      DPS1=DPSIAX(ARG(F1))
      DPS2=DPSIAX(ARG(F2))
      IF (NRCMP.LT.6) GOTO 7
   22 DT1=THETA1-THETES-DPS1-DTARB
      DT2=THETES-THETA2-DPS2+DTARB
      IF (DT1.GT.0.) GOTO 24
      DTARB=DT1+DTARB-1.E-6
      GOTO 22
   24 IF (DT2.GT.0.) GOTO 25
      DTARB=-(DT2-DTARB)+1.E-6
      GOTO 22
   25 DELTH1=DT1/(THETA1-THETES)
      DELTH2=DT2/(THETES-THETA2)
      GOTO 3
    6 IPAGE1=1
      IPAGE2=1
      NTYPE1=1
      NTYPE2=1
      DX1=0.05
      DX2=0.05
      IF (NRCMP.NE.2) GOTO 5
      TJML1=TJML1-XPAGE*TJML2
      TJML2=TJML2*(1.-XPAGE)
    5 IF (NRCMP-1) 1,2,2
C*****CALCULATION OF DISCRIMINATING STREAMLINE VELOCITY RATIOS
C     BASED ON THE RECOMPRESSION COEFFICIENT.  SINCE THE PRESSURE RATIO
C     ACROSS THE OBLIQUE SHOCK SYSTEM IS EQUAL FOR STREAMS 1 AND 2,
C     THE DISCRIMINATING STREAMLINE STAGNATION PRESSURE RATIO, P/POD,
C     IS ALSO THE SAME.
C
    1 PROD1=(1.0/(RECOMP*PRSHOK))
      PROD2=PROD1
      RECMP1=RECOMP
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```
      RECMP2=RECOMP
      GOTO 7
C*****CALCULATION OF DISCRIM- ATING STREAMLINE VELOCITY RATIO BASED ON
C     PAGE'S CRITERION, APPROXIMATED BY KORST, ITERATION FOR MORE EXACT
C     EVALUATION OF PAGE'S CRITERIONN (P/POD)D IS SIFFERENT FOR STREAM 1
C     AND STREAM 2.
    2 DELTH1=XKAPKO(EMNMSF (EMS1,GAMMA1))
      DELTH2=XKAPKO(EMNMSF (EMS2,GAMMA2))
    3 PROD1=PRSHK (EMS1,-(DELTH1*(THETA1-THETES)),GAMMA1)
      PROD2=PRSHK (EMS2,-(DELTH2*(THETA2-THETES)),GAMMA2)
      RECMP1=PROD1/PRSHOK
      RECMP2=PROD2/PRSHOK
      PROD1=1./PROD1
      PROD2=1./PROD2
C
C*****FOR STREAM 1.
    7 CSQD1D=CR2MSF(EMSPRF(PROD1,GAMMA1),GAMMA1)
      CSQD1 = CR2MSF(EMS1,GAMMA1)
      C1=SQRT  (CSQD1)
      CNR1 = SQRT  (CSQD1D/CSQD1)
      PHID1 = PHIDF(CNR1,TRBO1)
C*****FOR STREAM 2.
      CSQD2D = CR2MSF(EMSPRF(PROD2,GAMMA2),GAMMA2)
      CSQD2 = CR2MSF(EMS2,GAMMA2)
      C2=SQRT  (CSQD2)
      CNR2 = SQRT  (CSQD2D/CSQD2)
      PHID2 = PHIDF(CNR2,TRBO2)
C*****INTERATION FOR MORE EXACT PAGE-CRITERION
      IF (NRCMP.NE.2) GOTO 4
      DEL1=DELTH1
      DEL2=DELTH2
      DELTH1=XKAPPA(PHID1)
      DELTH2=XKAPPA(PHID2)
      VAR1=DELTH1-DEL1
      VAR2=DELTH2-DEL2
      IF (NTYPE1.NE.3) SIGN1=VAR1/ABS(VAR1)
      IF (NTYPE2.NE.3) SIGN2=VAR2/ABS(VAR2)
      IF (NTYPE1.NE.3) CALL ITER (DELTH1,DX1,1.E-4,SIGN1,VAR1,0.0,EPS,
     1IPAGE1,NTYPE1,XN1,YN1,XP1,YP1,NSIGA1,NSIGB1)
      IF (NTYPE2.NE.3) CALL ITER (DELTH2,DX2,1.E-4,SIGN2,VAR2,0.0,EPS,
     1IPAGE2,NTYPE2,XN2,YN2,XP2,YP2,NSIGA2,NSIGB2)
      IF (DELTH1.LE.0.) DELTH1=0.5*EPS
      IF (DELTH2.LE.0.) DELTH2=0.5*EPS
      IF (DELTH1.GT.1.) DELTH1=1.
      IF (DELTH2.GT.1.) DELTH2=1.
      IF (NTYPE1.EQ.3.AND.NTYPE2.EQ.3) GOTO 4
      IF (IPAGE1.GT.20.OR.IPAGE2.GT.20) GOTO 99
      GOTO 3
C*****EVALUATION OF BLEED AND ENERGY RATIOS.
    4 SIGMA1=12.0+2.758*EMNMSF(EMS1,GAMMA1)
      SIGMA2 =12.0+2.758*EMNMSF(EMS2,GAMMA2)
      IF (NRCMP-6) 27,26,27
   26 EI1D1=EPSIL1/(1.-CSQD1)
      EI1D2=EPSIL2/(1.-CSQD2)
      GOTO 28
   27 EI1D1=0.
      EI1D2=0.
   28 CALL TEGRAL(PHID1,CSQD1,TRBO1,EI1J1,EI1D1,EI3J1,EI3D1,ETAJ1,
     1           PHIJ1,EI2J1)
      CALL TEGRAL(PHID2,CSQD2,TRBO2,EI1J2,EI1D2,EI3J2,EI3D2,ETAJ2,
     1         PHIJ2,EI2J2)
C*****APPLICATION OF ONERA ANGULAR CRITERION
C     ACCOUNT FOR ORIGIN SHIFT
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```
      IF (ITC.GE.2) GOTO 9
      IF (NSHIFT.NE.0) GOTO 400
      TJML1=TJML1+SIGMA1*HLMT1/(EI2J1*(1.0-CSOD1))/CUROS(EMNMSF
     2(EMS1,GAMMA1))
      TJML2=TJML2+SIGMA2*HLMT2/(EI2J2*(1.0-CSOD2))/CUROS(EMNMSF
     2(EMS2,GAMMA2))
  400 IF(NSHIFT.NE.1) GOTO 9
      TJML1=TJML1+SIGMA1*HLMT1/(EI1J1*(1.-CSOD1))
      TJML2=TJML2+SIGMA2*HLMT2/(EI1J2*(1.-CSOD2))
    9 IF (NRCMP.LT.3) GOTO 8
      EMN1=EMNMSF(EMS1,GAMMA1)
      EMN2=EMNMSF(EMS2,GAMMA2)
      IF (NRCMP.EQ.6) GOTO 21
      PHICO1=PHICO(PHIJ1,ETAJ1,CSOD1,TRBO1)
      PHICO2=PHICO(PHIJ2,ETAJ2,CSOD2,TRBO2)
   11 DT1=-THETES+THETA1-DPSIAX(ARG(F1))-PSIO(EMN1,PHIJ1,GAMMA1)-DTARB
      DT2= THETES-THETA2-DPSIAX(ARG(F2))-PSIO(EMN2,PHIJ2,GAMMA2)+DTARB
      CO1=(DT1/PSIPHO(EMN1,PHIJ1,GAMMA1,TRBO1)/PHICO1-EPSIL1)
      CO2=(DT2/PSIPHO(EMN2,PHIJ2,GAMMA2,TRBO2)/PHICO2-EPSIL2)
      EI1D1=EI1J1+CO1/(1.-CSOD1)
      EI1D2=EI1J2+CO2/(1.-CSOD2)
      ENTR1=-CO1*TJML1/SIGMA1
      ENTR2=-CO2*TJML2/SIGMA2
      FAC1=0.
      FAC2=0.
      IF (NRCMP.EQ.5) FAC1=P2COSF(PHIJ1,ETAJ1,CSOD1,TRBO1)
       IF (NRCMP.EQ.5) FAC2=P2COSF(PHIJ2,ETAJ2,CSOD2,TRBO2)
      PHID1=PHIJ1+CO1*PHICO1*(1.-CO1*FAC1/2.)
      PHID2=PHIJ2+CO2*PHICO2*(1.-CO2*FAC2/2.)
      IF (PHID1.LE.1.E-3) GO TO 1000
      CALL TEGDSL(PHID1,CSOD1,TRBO1,EI1D1,EI3D1)
      GO TO 1001
 1000 EI1D1=0.0
      EI3D1=0.0
 1001 IF (PHID2.LE.1.E-3) GO TO 1002
      CALL TEGDSL(PHID2,CSOD2,TRBO2,EI1D2,EI3D2)
      GO TO 21
 1002 EI1D2=0.0
      EI3D2=0.0
   21 PRR1=PRMSF(EMS1,GAMMA1)/PRMSF(EMSMNF(EMN1*SQRT(1.-PHID1**2),GAMMA1
     1),GAMMA1)
      PRR2=PRMSF(EMS2,GAMMA2)/PRMSF(EMSMNF(EMN2*SQRT(1.-PHID2**2),GAMMA2
     1),GAMMA2)
      IF (NRCMP.LT.4) GOTO 10
      VAR=PRR1-PRR2
      IF (VAR.EQ.0.) GOTO 10
      SIGN=VAR/ABS(VAR)
      IF (ITMOST.NE.1.) DT=-(DTARB-DTARBO)/(VAR-VARO)*VAR
      DT=SIGN*DT
      VARO=VAR
      DTARBO=DTARB
      CALL ITER (DTARB,DT,1.E-4,SIGN,VAR,0.0,EPS,ITMOST,NTYPE,XN,YN,XP,
     1YP,NSIGA,NSIGB)
      IF (NRCMP.EQ.6.AND.(PRR1.LT.PRR2.AND.DT1.LT.2.E-6.OR.PRR1.GT.PRR2.
     1AND.DT2.LT.2.E-6)) GOTO 10
      IF (NTYPE.NE.3.AND.ITMOST.LT.1") GOTO (11,11,22),NJUMP
   10 THRSLP=(THETES+DTARB)*57.2958
      RECMP1=PRR1/PRSHOK
      RECMP2=PRR2/PRSHOK
    8 PRBN1=PRMSF(EMS1,GAMMA1)/PRMSF(EMSN1,GAMMA1)
      COEFF1=((1.0+COS (BETAN1))/SIGMA1)*(RIMP/RN1)*(TJML1/RN1)*(PRBN1)*
     1  SQRT  (2.0*GAMMA1/(GAMMA1-1.0))*(1.0/ATFLMS (EMSN1,GAMMA1))
      COEFF2= (TJML2/TJML1)*(SIGMA1/SIGMA2)*SQRT ((1.0/TRO21)*
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```
     1         (GAMMA2/GAMMA1)*(GC1/GC2)*((GAMMA1-1.0)/(GAMMA2-1.0)))
      COEFF3=(SIGMA1/SIGMA2)*(TJML2/TJML1)*SQRT ((GC2/GC1)*(TR021))*
     1        (((GAMMA2/GAMMA1)*((GAMMA1-1.0)/(GAMMA2-1.0))))**1.5)
      BLDR=-COEFF1*(C1*(EI1D1-EI1J1)+COEFF2*C2*(EI1D2-EI1J2))
      ENGR=-COEFF1*(C1*(EI3D1-TRBO1*EI1J1)+COEFF3*C2*
     1      (EI3D2-TRBO2*EI1J2))
      RETURN
   99 STOP
      END
      SUBROUTINE OUT2M(PRBE,PRBI1,PROEOI,TRBOE,TRBOI,TROEI,PROIE,
     1                 PRIIE,BLDR,ENGR,NPRINT,CP,CD,BLDRO,ENGRO)
C
C*****OUT2M WRITES OUT THE CALCULATED MIXING RESULTS AND CURRENT DATA.
C
C     ***VARIABLES***
C
C     PRB     = BASE PRESSURE RATIO, PB/PE.
C     PRBI1   = BASE PRESSURE RATIO,  PB/PI1.
C     PROEOI  = STAGNATION PRESSURE RATIO, POE/POI.
C     TRBOE   = BASE TEMPERATURE RATIO, TB/TOE.
C     TRBOI   = BASE TEMPERATURE RATIO, TB/TOI.
C     TROEI   = STAGNATION TEMPERATURE RATIO, TOE/TOI.
C     PROIE   = INTERNAL STAGNATION TO EXT. STATIC PRESS. RATIO, POI/PE.
C     PRIIE   = INPUT STATIC PRESSURE RATIO, PI1/PE.
C     BLDR,ENGR    = SEE SUBROUTINE *TJMIX* FOR DEFINITIONS.
C     NPRINT = SEE SUBROUTINE *INOUT*.
C     CP      = BASE PRESSURE COEFFICIENT.
C     CD      = BASE DRAG COEFFICIENT.
C     BLDRO,ENGRO = SPECIFIED VALUES OF THE BLEED AND ENERGY RATIOS.
C
C
      IF (NPRINT.LT.0) GO TO 103
C
      WRITE (3,100)          PRIIE,TROEI,PROEOI,PROIE,BLDRO,ENGRO
  100 FORMAT(19X, 41H ******TURBULENT JET MIXING RESULTS******, //,
     1  30X, 19H ***CURRENT DATA*** ,//,
     2  14X, 11H PI1/PE  = F8.5, 17X, 11H TOE/TOI = F8.5,//,
     3  14X, 11H POE/POI = F8.5, 17X, 11H POI/PE  =  F8.3 ,//,
     4  14X,  9H BLDRO = E12.5, 15X, 9H ENGRO = E12.5,//)
C
      WRITE (3,101)          BLDR,ENGR
  101 FORMAT(30X, 18H ***MIXING DATA***,//,
     1  14X,  8H BLDR = E12.5, 16X, 8H ENGR = E12.5,//)
C
      WRITE (3,102)          TRBOE,TRBOI,PRBE ,PRBI1,CP,CD
  102 FORMAT (16X,45H ***BASE PRESSURE AND TEMPERATURE RESULTS***  ,//,
     1  14X, 10H TB/TOE = F8.5, 18X, 10H TB/TOI = F8.5, //,
     2  14X, 10H PB/PE  = F8.5, 18X, 10H PB/PI1 = F8.5, //,
     3  14X, 10H CP-B   = F8.5, 18X, 10H CD-B   = F8.5 ,//,
     4  20X, 40H ******END OF CURRENT CASE RESULTS****** /,
     5  20X, 40H ****************************************, //)
C
  103 RETURN
      END
      SUBROUTINE ITER(X,DX,ERRORX,SIGN,Y,YGIVEN,ERRORY,NIT,NTYPE,
     1                XNEG,YNEG,XPOS,YPOS,NSIGN1,NSIGN2)
C
C*****SUBROUTINE PERFORMS AN ITERATION TO FIND X SUCH THAT THE ABSOLUTE
C     VALUE OF (Y-YGIVEN) IS LESS THAN OR EQUAL TO ERRORY OR THE
C     ABSOLUTE VALUE OF (X(I+1)-X(I)) IS LESS THAN OR EQUAL TO ERRORX.
C
C     ***VARIABLES***
C
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```
C      X       = INDEPENDENT VARIABLE.
C      DX      = INCREMENT IN INDEPENDENT VARIABLE.
C      ERRORX  = MAXIMUM VALUE OF ABS(X(I+1)-X(I)) FOR SOLUTION.
C      SIGN    = +1.0 OR -1.0, DEFINES INCREMENTING FROM X INITIAL.
C      Y       = DEPENDENT VARIABLE.
C      YGIVEN  = GIVEN VALUE OF DEPENDENT VARIABLE.
C      ERRORY  = MAXIMUM VALUE OF ABS(Y-YGIVEN).
C      NIT     = INCREMENT NUMBER.
C      NTYPE   = 1, INCREMENT.
C              = 2, INTERPOLATION.
C              = 3, SOLUTION.
C
      DY=Y-YGIVEN
      IF(ABS (DY)-ERRORY) 90,90,10
   10 IF(DY) 20,90,30
   20 NSIGN2=-1
      XNEG=X
      YNEG=Y
      GO TO 40
   30 NSIGN2=+1
      XPOS=X
      YPOS=Y
   40 GO TO (50,80), NTYPE
   50 IF(NIT-1) 70,70,60
   60 NSIGN=NSIGN1*NSIGN2
      IF(NSIGN) 80,80,70
   70 NSIGN1=NSIGN2
      NIT=NIT+1
C*****INCREMENT TO FIND SOLUTION INTERVAL.
      X=X+SIGN*DX
      GO TO 100
   80 NTYPE=2
C*****INTERPOLATION FOR SOLUTION.
      NIT=NIT+1
      XSAVE=X
      RATIO=(XPOS-XNEG)/(YPOS-YNEG)
      X=XNEG+RATIO*(YGIVEN-YNEG)
C*****ACCELERATION OF CONVERGENCE OF ITERATION--REF. WEGSTEIN, NBS.
      A = 1.0/RATIO
      IF(A-1.0) 82,88,82
   82 Q = A/(A-1.0)
      XWGSTN = Q*XSAVE + (1.0-Q)*X
      IF(XNEG-XWGSTN) 84,86,88
   84 IF(XWGSTN-XPOS) 86,86,88
   86 X=XWGSTN
   88 IF(ABS(X-XSAVE) - ERRORX) 90,90,100
   90 NTYPE=3
  100 RETURN
      END
      SUBROUTINE ABTS(GAMMA,EMS1,XBT1,RBT1,ANGBT1,XBT2,RBT2,NSHAPE,
     1                NPRINT,NOCPTS,NERROR,CD)
C
C*****************************************************************
C
C     A X I S Y M M E T R I C   B O A T T A I L   S U B P R O G R A M
C
C*****************************************************************
C
C     WRITTEN BY --- A. L. ADDY
C
C     NOTE --- INPUT AND OUTPUT DATA ARE FOR THE *UPPER-HALF* OF FLOW
C              FIELD. THE ADJUSTMENT OF THESE DATA FOR THE CALCULATIONS
C              IS MADE INTERNALLY.
```

```
C
C     SUBPROGRAM REQUIRES --- OUTBT1,EMSPM,PPS,RIMPS,MCDATA,OUTBT2,
C                             BTITER.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     EMS1   = INITIAL FREESTREAM MACH STAR AT STATION 1.
C     XBT1,RBT1 = COORDINATES OF FIRST POINT ON BOATTAIL.
C     ANGBT1 = INITIAL BOATTAIL ANGLE AT STATION 1.
C              NEGATIVE AND IN RADIANS.
C     XBT2,RBT2 = FINAL POINT ON BOATTAIL.
C     NSHAPE = SEE SUBROUTINE *BTCNST*.
C     NPRINT = -1 OR 0, B.B.P. DATA NOT PRINTED.
C              +1, B.B.P. DATA PRINTED.
C     NOCPTS = NUMBER OF II-CHAR. POINTS CALCULATED ON CHAR. THROUGH (2)
C     NERROR = SEE SUBROUTINE *BTITER*.
C
C     ***OUTPUT DATA (IN ORDER)***
C
C     INPUT DATA TO ABTS
C     X      = LONGITUDINAL COORDINATE OF BOUNDARY POINT.
C     R      = RADIAL COORDINATE OF BOUNDARY POINT.
C     THETA  = LOCAL FLOW ANGLE AT BOUNDARY POINT (IN DEGREES).
C
C     NOTE --- THE II-CHAR. DATA THROUGH (XBT2,RBT2) IS TRANSMITTED TO
C              THE MASTER PROGRAM THROUGH *COMMON* IN THE ARRAY CHARE.
C
C
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1   P3(5), CIID(5)
      COMMON PMB,CHARI,CHARE,P1,P2,P3
      PRMSF(EMS,GAMMA)=(1.0-((GAMMA-1.0)/(GAMMA+1.0))*EMS**2)**
     1                 (GAMMA/(GAMMA-1.0))
      EMNMSF(EMS,GAMMA)=SQRT  (((2.0*(EMS**2))/(GAMMA+1.0))/
     1                 (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))  )
      CALL BTCNST(XBT1,RBT1,ANGBT1,XBT2,RBT2,NSHAPE,C1,C2,C3)
C*****INPUT DATA, SOME OUTPUT DATA, AND COLUMN HEADINGS ARE PRINTED.
      CALL OUTBT1(GAMMA,EMS1,XBT1,RBT1,ANGBT1,XBT2,RBT2,NSHAPE,
     1            C1,C2,C3,NPRINT)
C*****SET INITIAL VALUES.
      NGOTO=1
      NOCPTS=1
      NI=1
      PR101=PRMSF(EMS1,GAMMA)
      EMN1=EMNMSF(EMS1,GAMMA)
C*****NUMBER OF POINTS CALCULATED ON THE II-CHARACTERISTIC ORIGINATING
C     AT (XBT2,RBT2) IS SPECIFIED HERE.   (LIMITE MAX. = 30).
C
      LIMITE=30
C*****FOR UNIFORM FLOW.
      EMS=EMS1
      DR=0.02*RBT1
      DX=SQRT  (EMN1**2-1.0)*DR
      GO TO 30
C*****LOAD INITIAL VALUES AT (XBT1,RBT1) INTO THE PMB ARRAY.
   30 PMB(1,1,1)=XBT1
      PMB(1,2,1)=RBT1
      PMB(1,3,1)=EMS
      PMB(1,4,1)=0.0
      IF(ABS (ANGBT1)-1.0E-3) 40,40,50
C*****BOATTAIL WITH ZERO INITIAL TURNING ANGLE.
   40 K=0
```

```
      GO TO 70
C*****FOR AN AFTERBODY WITH INITIAL TURNING ANGLE.
   50 IF (ANGBT1) 52,52,54
C*****FOR A BOATTAIL (BETA2E NEGATIVE).
   52 K=(ABS (57.29578*ANGBT1)+1.0)
      GO TO 56
C*****APPROXIMATE ANALYSIS FOR A FLARE (BETA2E POSITIVE).
   54 K = 1
   56 FK = K
      DTA=ANGBT1/FK
C*****CALCULATION OF CHAR. ARRAY DATA FOR POINTS L=1,K+1 AND N=1.
      DO 60 L=1,K
      PMB(L+1,1,1)=PMB(L,1,1)
      PMB(L+1,2,1)=PMB(L,2,1)
      PMB(L+1,4,1)=PMB(L,4,1) + DTA
   60 PMB(L+1,3,1)=EMSPM(PMB(1,3,1),PMB(1,4,1),PMB(L+1,4,1),GAMMA)
C*****K1 IS NUMBER OF FAMILY II CHAR. FOR SUBDIVIDED EXPANSION.
   70 K1=K+1
C*****THE INITIAL BOUNDARY POINT DATA IS PRINTED.
      DO 80 M=1,4
   80 P3(M)=PMB(K1,M,1)
      CALL OUTBT2(GAMMA,EMS1,EMN1,PR1U1,P3,NI,NGOTO,NPRINT,CD)
C*****THE FLOW FIELD CALCULATIONS ARE NOW MADE ALONG FAMILY I
C     CHARACTERISTICS STARTING FROM THE INPUT POINTS ON THE SUBDIVIDED
C     INITIAL FAMILY FOR THE FIRST AND SUBSEQUENT AXIS POINTS.
   82 NI=NI+1
C*****CALCULATION OF THE INITIAL II-CHARACTERISTIC DATA POINT.
C*****LOAD CURRENT II-CHARACTERISTICS DATA POINTS INTO PMB ARRAY.
      PMB(1,1,2)=PMB(1,1,1) + DX
      PMB(1,2,2)=PMB(1,2,1) + DR
      PMB(1,4,2)=PMB(1,4,1)
      PMB(1,3,2)=EMS
      GO TO (90,90,100), NGOTO
   90 DO 92 M=1,4
   92 CIID(M)=PMB(1,M,2)
      GO TO 98
   94 DO 96 M=1,4
   96 PMB(1,M,2)=CIID(M)
   98 IF(K) 140,140,100
C*****CALCULATIONS ARE FOR THE CURRENT N-TH POINT ON THE INITIAL
C     FAMILY II CHARACTERISTIC.
C
  100 DO 110 L=1,K
C*****CALCULATIONS ARE FOR THE CURRENT L-TH EXPANSION INCREMENT.
C*****LOAD DATA/ FIELD POINT CALCULATION/ STORE DATA.
      CALL MCDATA(1,L,L+1,L3,KPTS)
      CALL FPS(GAMMA,P1,P2,P3,NERROR)
      IF(NERROR) 200,110,110
  110 CALL MCDATA(2,L1,L2,L+1,KPTS)
C*****ALL FIELD POINTS ON N-TH FAMILY I CHAR. HAVE BEEN CALCULATED.
      GO TO (140,140,120), NGOTO
C*****STORE BOATTAIL II-CHARACTERISTIC DATA.
  120 NOCPTS=NOCPTS+1
      DO 130 M=1,4
  130 CHARE (M,NOCPTS)=P3(M)
C*****CHARACTERISTICS DATA SHIFT.
      CALL MCDATA(3,L1,L2,L3,K+1)
      IF(NOCPTS-LIMITE) 82,200,200
C*****LOAD DATA/ BOUNDARY POINT CALCULATION/ STORE DATA.
  140 CALL MCDATA(1,K+1,K+1,L3,KPTS)
      CALL  BTBPS(GAMMA,P1,P2,P3,NSHAPE,C1,C2,C3,NERROR)
      IF(NERROR) 200,144,144
C*****CONTINUE BOATTAIL CALCULATION, ITERATE FOR I-CHARACTERISTIC
```

```
C     THROUGH THE BOATTAIL END POINT (XBT2,RBT2), OR CALCULATE THE
C     II-CHARACTERISTIC ORIGINATING AT THE POINT (XBT2,RBT2).
C
  144 CALL BTITER(XBT1,XBT2,P3,C110,NGOTO,NERROR)
      IF(NERROR) 200,146,146
  146 GO TO (170,94,150), NGOTO
C*****LOAD FIRST BOATTAIL II-CHARACTERISTIC POINT.
  150 DO 160 M=1,4
  160 CHARE (M,1)=P3(M)
  170 CALL MCDATA(2,L1,L2,K+2,KPTS)
C*****THE CURRENT BOUNDARY POINT DATA IS NOW PRINTED.
      CALL OUTBT2(GAMMA,EMS1,EMN1,PR101,P3,N1,NGOTO,NPRINT,CD)
C*****CHARACTERISTICS DATA SHIFT.
      CALL MCDATA(3,L1,L2,L3,K+2)
C*****ADVANCE INDEX FOR NEXT INPUT POINT ON INITIAL CHARACTERISTIC.
      K=K+1
      GO TO 82
  200 RETURN
      END
      SUBROUTINE BTCNST(XBT1,RBT1,ANGBT1,XBT2,RBT2,NSHAPE,C1,C2,C3)
C
C     ***VARIABLES***
C
C     XBT1   = INITIAL LONGITUDINAL BOATTAIL COORDINATE.
C     RBT1   = INITIAL RADIAL BOATTAIL COORDINATE.
C     ANGBT1 = INITIAL BOATTAIL TURNING ANGLE, RADIANS, CC=(+).
C     XBT2   = TERMINAL LONGITUDINAL BOATTAIL COORDINATE.
C     RBT2   = TERMINAL RADIAL BOATTAIL COORDINATE.
C     NSHAPE = 1, OGIVE BOATTAIL.
C            = 2, PARABOLIC BOATTAIL.
C            = 3, CONICAL BOATTAIL.
C     C1,C2,C3 = COEFFICIENTS IN THE BOATTAIL PROFILE EQUATIONS.
C
C
      SLOPE1= TAN (ANGBT1)
      GO TO (10,20,30), NSHAPE
C*****OGIVE BOATTAIL (NSHAPE=1).
   10 C1=(0.5)*(  (XBT2-XBT1)**2-2.0*SLOPE1*RBT1*(XBT2-XBT1)+RBT2**2
     1    -RBT1**2)  /  (RBT2-RBT1-1.0*SLOPE1*(XBT2-XBT1)  )
      C2= XBT1 + SLOPE1*(RBT1-C1)
      C3= (XBT1-C2)**2 + (RBT1-C1)**2
      GO TO 40
C*****PARABOLIC BOATTAIL (NSHAPE=2).
   20 C1=( RBT2-RBT1-SLOPE1*(XBT2-XBT1) ) /
     1     ( XBT1**2+XBT2**2 -2.0*XBT1*XBT2 )
      C2=SLOPE1 -2.0*C1*XBT1
      C3=RBT1 -   ( C2*XBT1 + C1*(XBT1**2) )
      GO TO 40
C*****CONICAL BOATTAIL (NSHAPE=3).
   30 C1=RBT1
      C2=SLOPE1
      C3=XBT1
      RBT2=RBT1+SLOPE1*(XBT2-XBT1)
C
   40 RETURN
      END
      SUBROUTINE OUTBT1(GAMMA,EMS1,XBT1,RBT1,ANGBT1,XBT2,RBT2,NSHAPE,
     1                   C1,C2,C3,NPRINT)
C
C*****THIS SUBROUTINE PRINTS INPUT DATA, SOME OUTPUT DATA, AND
C     HEADINGS FOR THE BOATTAIL CALCULATIONS.
C
      PRMSF(EMS,GAMMA)=(1.0-((GAMMA-1.0)/(GAMMA+1.0))*EMS**2)**
```

```
     1                  (GAMMA/(GAMMA-1.0))
      EMNMSF(EMS,GAMMA)=SQRT  (((2.0*(EMS**2))/(GAMMA+1.0))/
     1                  (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))  )
      IF(NPRINT) 10,10,100
  100 EMN1=EMNMSF(EMS1,GAMMA)
      PR101=PRMSF(EMS1,GAMMA)
      BETAD=57.2958*ANGBT1
C
      WRITE (3,1)            GAMMA,EMN1,PR101
    1 FORMAT(1H1,///,21X,23H AXISYMMETRIC BOATTAIL /,
     1 15X,30H WITH UNIFORM SUPERSONIC FLOW //,
     2 21X,20H *** INPUT DATA *** //,
     3 7X,9H GAMMA = F5.3,3X,12H MACH NO. = F5.3,3X, 8H P/PO = F6.4//)
C
      GO TO (2,4,6), NSHAPE
C
    2 WRITE (3,3)
    3 FORMAT(1H ,19X,27H * OGIVE BOATTAIL PROFILE *)
      GO TO 8
C
    4 WRITE (3,5)
    5 FORMAT(1H ,19X,32H * PARABOLIC BOATTAIL PROFILE * )
      GO TO 8
C
    6 WRITE (3,7)
    7 FORMAT(1H ,19X,30H * CONICAL BOATTAIL PROFILE * )
C
    8 WRITE (3,9)            XBT1,RBT1,BETAD,XBT2,RBT2,C1,C2,C3
    9 FORMAT(1H ,//,7X, 8H XBT1 = F6.3,3X, 8H RBT1 = F6.3,
     1 4X,10H ANGBT1 = F8.3//,7X,8H XBT2 = F6.3,3X,8H RBT2 = F6.3//,
     2 7X,8H C1    = F7.3,2X,8H C2    = F7.3,3X,10H C3      = F7.3///,
     3 20X,37H *** BOATTAIL SURFACE OUTPUT DATA *** //,
     4 12X,1HX,14X,1HR,10X,8HMACH NO.,9X,4HP/P1,9X,9HCP(LOCAL) //)
C
   10 RETURN
      END
      SUBROUTINE BTBPS(GAMMA,P1,P2,P3,NSHAPE,C1,C2,C3,NERROR)
C
C     B O A T T A I L   B O U N D A R Y   P O I N T
C     S U B R O U T I N E  ( B T B P S ) .
C
C*****THIS SUBROUTINE CALCULATES A POINT P3 ON THE BOATTAIL WALL
C     GIVEN THE PROPERTIES OF A POINT P1 IN THE FLOW FIELD.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     PI(J)  = J-TH FLOW VARIABLE AT THE POINT I WHERE I=1,2,OR 3.
C     P1(J) AND P2(J),J=1,5 = FLOW VARIABLES AT KNOWN POINTS 1 AND 2.
C     P3(J),J=1,5 = FLOW VARIABLES AT THE UNKNOWN POINT 3.
C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C               J=1 CORRESPONDS TO X.
C               J=2 CORRESPONDS TO R.
C               J=3 CORRESPONDS TO MACH STAR (EMS).
C               J=4 CORRESPONDS TO THETA IN RADIANS (THET).
C     NSHAPE = SEE BELOW.
C     C1,C2,C3 = CONSTANTS IN THE BOATTAIL PROFILE EQUATIONS.
C     NERROR = A CONTROL VARIABLE FOR CHECKING THE POSSIBILITY THAT
C               THE CURRENT CHARACTERISTIC MISSES THE BOATTAIL AND AN
C               ITERATION IS REQUIRED.
C               NERROR =-1 ... ERROR IN CALCULATION.
C               NERROR = 0 ... NO ITERATION REQUIRED.
C               NERROR = 1 ... AN ITERATION IS REQUIRED.
```

```
C
C
C     POINTS 1 AND 3 ARE ASSUMED CONNECTED BY FAMILY I WHERE
C     POINT 3 IS ON THE WALL.
C
C     THE BOATTAIL PROFILE IS SPECIFIED BY EQUATIONS OF THE FORM---
C
C               1.  IF NSHAPE=1      OGIVE
C                   R= C1 + SQRT( C3 - (X-C2)**2 )
C
C               2.  IF NSHAPE=2      PARABOLIC
C                   R= C3 + C2*X + C1*(X**2)
C
C               3.  IF NSHAPE=3      CONICAL
C                   R= C1 + C2*(X-C3)
C
C     WHERE C1,C2,AND C3 HAVE BEEN CALCULATED FROM THE INPUT DATA
C     IN SUBROUTINE *BTCNST*.
C
C
      DIMENSION P1(5), P2(5), P3(5)
      ALPHAF(EMSTAR,GAMMA)=ATAN (SQRT((1.0 - ((GAMMA-1.0)/(GAMMA+1.0))
     1   *(EMSTAR**2))/(EMSTAR**2-1.0)))
      AVGF(A,B) = (A + B)/2.0
      PCOEFF(EMSTAR,ALPHA)=EMSTAR*TAN (ALPHA)
      QCOEFF(NPOINT,RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*
     1   (TAN (ALPHA)**2)*TAN (THETA))/(TAN (THETA) + ((-1.0)**NPOINT)*
     2   TAN (ALPHA))
      HOCOEF (RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*TAN (ALPHA)*
     1    SIN (ALPHA)*SIN (THETA))
C*****NPOINT IN  QCOEFF()  INDICATES THE KNOWN POINT BEING USED--1 OR 2.
C*****ERROR FLAG SET.
      NERROR=0
      NCOUNT=0
      NCTMAX=15
      EMSMAX=SQRT  ((GAMMA+1.0)/(GAMMA-1.0))
C*****KNOWN INPUT DATA FROM POINTS 1 AND 2.
      X1=P1(1)
      R1=P1(2)
      EMS1=P1(3)
      THET1=P1(4)
      R2=P2(2)
      EMS2=P2(3)
      THET2=P2(4)
C*****FOR AN INITIAL ESTIMATE OF THE VALUES AT POINT 3.
      R3=AVGF(R1,R2)
      EMS3=AVGF(EMS1,EMS2)
      THET3=AVGF(THET1,THET2)
      GO TO 17
C*****ITERATION FOR VARIABLES AT POINT 3.
C*****IF NSHAPE = 1,  OGIVE.
    1 A=1.0 + (TAN (DIFF13))**2
      B=2.0*(R1-C1)*TAN (DIFF13) -2.0*C2-2.0*X1*(TAN (DIFF13) )**2
      C= C2**2 - C3 + (   (R1-C1)-X1*TAN (DIFF13) )**2
      DISCR=B**2-4.0*A*C
      IF(DISCR) 19,19,3
    3 X3=(-B-SQRT, (B**2-4.0*A*C))/(2.0*A)
      R3=R1+(X3-X1)*TAN (DIFF13)
      THET3=ATAN ( (C2-X3)/(R3-C1) )
      GO TO 10
C*****IF NSHAPE = 2,  PARABOLIC.
    4 A=C1
      B=C2-TAN (DIFF13)
```

```
      C=C3-R1+X1*(TAN (DIFF13))
      DISCR=B**2-4.0*A*C
      IF(DISCR) 19,19,6
    6 X3= (-B+SQRT  (B**2-4.0*A*C))/(2.0*A)
      R3=R1+(X3-X1)*TAN (DIFF13)
      THET3=ATAN (C2+2.0*C1*X3)
      GO TO 10
C*****IF NSHAPE = 3,  CONICAL.
    7 X3= (C1-R1-C2*C3+X1*TAN (DIFF13) ) / (TAN (DIFF13) - C2 )
      R3=R1+(X3-X1)*TAN (DIFF13)
      IF(R3) 19,19,9
    9 THET3=ATAN (C2)
C*****TEST AND EVALUATION FOR HORIZONTAL I-CHARACTERISTICS.
   10 IF(ABS (DIFF13)-1.0E-3) 11,11,12
C*****FOR I HORIZONTAL.
   11 PROD13=HQCOEF (R13,EMS13,THET13,ALPH13)*(X3-X1)
      GO TO 13
C*****FOR I-CHARACTERISTIC, O.K.
   12 PROD13=QCOEFF(1,R13,EMS13,THET13,ALPH13)*(R3-R1)
C*****CALCULATION OF FLOW VARIABLES AT POINT 3.
   13 EMS3=EMS1-P13*(THET3-THET1)+PROD13
      DIFFMS=(EMS3-SAVE1)/SAVE1
      IF((EMS3.LT.1.0) .OR. (EMS3.GT.EMSMAX)) GO TO 20
      IF(ABS (DIFFMS) .LE. 1.0E-4) GO TO 18
   17 NCOUNT=NCOUNT+1
      IF(NCOUNT .GT. NCTMAX)  GO TO 18
      SAVE1 = EMS3
      R13=AVGF(R1,R3)
      EMS13=AVGF(EMS1,EMS3)
      THET13=AVGF(THET1,THET3)
      ALPH13=ALPHAF(EMS13,GAMMA)
      DIFF13=THET13-ALPH13
      P13=PCOEFF(EMS13,ALPH13)
      GO TO (1,4,7), NSHAPE
   18 P3(1) = X3
      P3(2)=R3
      P3(3)=EMS3
      P3(4)=THET3
      IF(NCOUNT .GT. NCTMAX)  WRITE (3,180) NCOUNT,DIFFMS
  180 FORMAT(/, 5X,37H *** CONVERGENCE ERROR IN *BTBPS*, ( ,I3,2H , ,
     1   E10.3,6H ) ***  /)
      RETURN
   19 NERROR=+1
      RETURN
   20 NERROR=-1
      WRITE (3,21)
   21 FORMAT(//,23X,32H *** ERROR IN  *BTBPS* CALC. ***  //)
      RETURN
      END
      SUBROUTINE OUTBT2(GAMMA,EMS1,EMN1,PR101,P3,N1,NGOTO,NPRINT,CD)
C
C*****THIS SUBROUTINE PRINTS THE CALCULATED BOATTAIL SURFACE DATA
C     AT THE LOCATION, N= NOBPTS, IN THE BPTS(M,N) ARRAY.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     EMS1   = FREESTREAM MACH STAR.
C     EMN1   = FREESTREAM MACH NUMBER.
C     PR101  = FREESTREAM STATIC-TO-STAGNATION PRESSURE RATIO.
C     P3(J)  = BOATTAIL BOUNDARY POINT DATA.
C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C             J=1 CORRESPONDS TO X.
```

```
C               J=2 CORRESPONDS TO R.
C               J=3 CORRESPONDS TO MACH STAR (EMS).
C               J=4 CORRESPONDS TO THETA IN RADIANS (THETA).
C     NI      = 1, ...    LOCATES THE BOUNDARY POINT ON THE BOATTAIL
C                         SURFACE.
C     NGOTO   = 1, NORMAL BOATTAIL CALCULATION.
C             = 2, ITERATION FOR I-CHARACTERISTIC THROUGH (XBT2,RBT2).
C             = 3, CALCULATION OF II-CHARACTERISTIC THROUGH (XBT2,RBT2).
C     NPRINT = SEE SUBROUTINE *ABTS*.
C
C
      DIMENSION P3(5)
      PRMSF(EMS,GAMMA)=(1.0-((GAMMA-1.0)/(GAMMA+1.0))*EMS**2)**
     1                  (GAMMA/(GAMMA-1.0))
      EMNMSF(EMS,GAMMA)=  SQRT(((2.0*(EMS**2))/(GAMMA+1.0))/
     1                  (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))  )
      IF(NPRINT) 80,80,10
   10 X=P3(1)
      R=P3(2)
      EMS=P3(3)
      EMN=EMNMSF(EMS,GAMMA)
      PROBO1=1.0
      PRB1=(PRMSF(EMS,GAMMA)/PR101)*PROBO1
C*****THE LOCAL PRESSURE COEFFICIENT IS CALCULATED.  CP IS BASED ON
C     THE FREESTREAM MACH NUMBER AND PRESSURE.
C
      CP=(PRB1-1.0)/(0.5*GAMMA*(EMN1**2))
      WRITE (3,20) X,R,EMN,PRB1,CP
   20 FORMAT(7X,F10.5,5X,F10.5,5X,F10.5,5X,F10.5,5X,F10.5)
C*****THE BOATTAIL DRAG COEFFICIENT IS CALCULATED.  CD IS REFERENCED
C     TO THE FREESTREAM PRESSURE AND MACH NUMBER CONDITIONS.
C
      IF(NI-1) 30,30,40
C*****INITIALIZE CD CALCULATION.
   30 CD=0.0
      DENOM=0.5*GAMMA*(EMN1**2)*(R**2)
      GO TO 50
   40 AVGPR=(0.5*(PRMSF(EMSL,GAMMA)+PRMSF(EMS,GAMMA))*PROBO1)/PR101
      CD=CD+(((1.0-AVGPR)*(RL**2-R**2))/DENOM)
   50 RL=R
      EMSL=EMS
      GO TO (80,80,60), NGOTO
   60 WRITE (3,70) CD
   70 FORMAT(/,25X,28H *** DRAG COEFFICIENT, CD = F8.5,3H*** , //)
   80 RETURN
      END
      SUBROUTINE BTITER(XBT1,XBT2,P3,C1ID,NGOTO,NERROR)
C
C*****SUBROUTINE CONTROLS BOATTAIL ITERATION FOR I-CHARACTERISTIC
C     PASSING THROUGH (XBT2,RBT2).
C
C     ***VARIABLES***
C
C     XBT2    = LONGITUDINAL COORD. OF TERMINAL POINT OF THE BOATTAIL.
C     P3      = CURRENT BOUNDARY POINT FROM SUBROUTINE *BTBPS*.
C     C1ID    = CURRENT INITIAL II-CHARACTERISTIC DATA POINT.
C     NGOTO   = 1, BOATTAIL CALCULATION.
C             = 2, ITERATION FOR I-CHARACTERISTIC THROUGH (XBT2,RBT2).
C             = 3, CALCULATION OF II-CHARACTERISTIC THROUGH (XBT2,RBT2).
C     NERROR = -1, ERROR IN ITERATION, GO TO NEXT CASE.
C             = 0, BOUNDARY POINT CALCULATION O.K.
C             = 1, ERROR IN BOUNDARY POINT CALCULATION, START ITERATION.
C
```

```
C
      DIMENSION P3(5), SAVEL(5), SAVER(5), CIID(5)
      XBT = (XBT2-XBT1)
C*****ERROR OR ITERATION DETECTION.
      GO TO (10,60), NGOTO
   10 IF(NERROR) 20,20,50
   20 IF(XBT2-P3(1)) 50,190,30
   30 ITER=1
      DO 40 M=1,4
   40 SAVEL(M)=CIID(M)
      RETURN
C*****ITERATION SEQUENCE.
   50 NGOTO=2
   60 IF(NERROR) 70,70,110
   70 IF(ABS((XBT2-P3(1))/XBT)-1.0E-4) 190,190,80
   80 IF(XBT2-P3(1)) 110,190,90
   90 DO 100 M=1,4
  100 SAVEL(M)=CIID(M)
      GO TO 130
  110 DO 120 M=1,4
  120 SAVER(M)=CIID(M)
  130 IF(ITER-15) 160,160,140
  140 NERROR=-1
      WRITE (3,150)
  150 FORMAT(//,5X,67H *** MAX. NO. ITERATIONS EXCEEDED IN SBR. BTITER.
     1 GO TO NEXT CASE. //)
      RETURN
  160 IF(ABS ((SAVEL(1)-SAVER(1))/XBT)-1.0E-4) 190,190,170
  170 ITER=ITER+1
C*****INTERVAL HALVE FOR VALUES ON INITIAL II-CHARACTERISTIC.
      DO 180 M=1,4
  180 CIID(M)=0.5*(SAVEL(M)+SAVER(M))
      RETURN
C*****SOLUTION FOUND.
  190 NGOTO=3
      RETURN
      END
      SUBROUTINE UFLOC(GAMMA,EMS,XC,RC,N1,CHAR,NFLOW)
C
C*****THIS SUBROUTINE SUBDIVIDES THE INITIAL FAMILY II CHARACTERISTIC
C     AND CALCULATES THE INPUT DATA FOR POINTS ON THIS CHARACTERISTIC
C     FOR UNIFORM FLOW.
C
C     ***VARIABLES***
C
C     GAMMA = RATIO OF THE SPECIFIC HEATS.
C     EMS   = APPROACH MACH STAR.
C     XC    = LONGITUDINAL COORDINATE WHERE EXPANSION IS CENTERED.
C     RC    = RADIAL COORDINATE WHERE EXPANSION IS CENTERED.
C             NEGATIVE FOR INTERNAL FLOW AND POSITIVE FOR EXTERNAL FLOW.
C     N1    = NUMBER OF INCREMENTS OF INITIAL CHAR. (MAX. IS 29)
C     CHAR  = INITIAL CHARACTERISTIC DATA ARRAY.
C     NFLOW = 1, INTERNAL FLOW.
C           = 2, EXTERNAL FLOW.
C
C
      DIMENSION CHAR(5,30)
      EMNMSF(EMS,GAMMA)=SQRT(((2.0*(EMS**2))/(GAMMA+1.0))/
     1                   (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))   )
      GO TO (10,20), NFLOW
C*****FOR INTERNAL FLOW.
   10  N1=15
      FN1=N1
```

```
      DR=ABS (RC)/FN1
      GO TO 30
C*****FOR EXTERNAL FLOW.
   20 DR=0.03*ABS (RC)
   30 DX=DR*SQRT((EMN*SF(EMS,GAMMA))**2-1.0)
      NPTS=N1+1
      DO 40 N=1,NPTS
      FN=N-1
      CHAR (1,N) = XC + FN*DX
      CHAR (2,N) = RC + FN*DR
      CHAR (3,N) = EMS
   40 CHAR (4,N) = 0.0
      RETURN
      END
      SUBROUTINE CNFLOC(GAMMA,EMS,BETA,XC,RC,N1)
C
C*****FOR INTERNAL CONICAL FLOW, THIS SUBROUTINE SUBDIVIDES THE
C     NON-CHARACTERISTIC UNIFORM FLOW CURVE THROUGH THE POINT (XC,RC)
C     AND THEN CALCULATES THE INPUT DATA ALONG THE FAMILY II
C     CHARACTERISTIC WHICH ORIGINATES AT THIS POINT.
C
C     SUBROUTINE REQUIRES---FPS,APS.
C
C     ***VARIABLES***
C
C     GAMMA = RATIO OF THE SPECIFIC HEATS.
C     EMS   = APPROACH MACH STAR.
C     BETA  = FLOW ANGLE, NEGATIVE, (IN RADIANS), AT (XC,RC).
C     XC    = LONGITUDINAL COORDINATE WHERE EXPANSION IS CENTERED.
C     RC    = RADIAL COORDINATE WHERE EXPANSION IS CENTERED.
C     N1    = NUMBER OF INCREMENTS OF INITIAL CHAR. (MAX. IS 29)
C
C
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1   P3(5)
      COMMON PMB, CHARI, CHARE, P1, P2, P3
C
      RCONE=RC/SIN (BETA)
C*****SUBDIVISION OF THE NON-CHARACTERISTIC CURVE INTO N2 INCREMENTS.
C     (N1=2*N2).  TO CHANGE THE NUMBER OF INCREMENTS CHANGE ONLY N2.
C     (MAXIMUM N2 IS 14).
C
      N2=10
      FN2=N2
      N1=2*N2
C*****STORE INITIAL DATA POINT.
      PMB(1,1,1)=XC
      PMB(1,2,1)=RC
      PMB(1,3,1)=EMS
      PMB(1,4,1)=BETA
      DO 10 M=1,4
   10 CHARI(M,1)=PMB(1,M,1)
C*****THE FLOW FIELD CALCULATIONS ARE NOW MADE ALONG FAMILY I
C     CHARACTERISTICS STARTING FROM THE POINTS ON THE SUBDIVIDED
C     NON-CHARACTERISTICS CURVE.  THIS SEQUENCE IS NOT APPLICABLE FOR
C     CALCULATIONS INVOLVING OTHER THAN THE FIRST AXIS POINT.
C*****THE CALCULATED FLOW FIELD DATA FOR THE (N1+1) POINTS ON THE
C     FAMILY II CHARACTERISTIC ORIGINATING AT (XC,RC) WILL BE STORED AT
C     CHARI(M,N), WHERE N=1,N1+1.
C
      DO 40 N=1,N2
C*****CALCULATE DATA ON THE NON-CHARACTERISTIC INPUT CURVE.
      FN=N
```

```
      ANGLER=BETA*(1.0-FN/FN2)
      PMB(N+1,1,2)=XC+RCONE*(COS(ANGLER)-COS(BETA))
      PMB(N+1,2,2)=RCONE*SIN(ANGLER)
      PMB(N+1,3,2)=EMS
      PMB(N+1,4,2)=ANGLER
      KPTS=N+1
      DO 20 I=1,N
      L=N-I+1
C*****LOAD DATA/ CALCULATE FIELD POINT/ STORE DATA.
      CALL MCDATA(1,L+1,L,L3,KPTS)
      CALL FPS(GAMMA,P1,P2,P3,NERROR)
      CALL MCDATA(2,L1,L2,L,KPTS)
   20 CONTINUE
C*****STORE INITIAL CHARACTERISTICS DATA.
      DO 30 M=1,4
   30 CHARI(M,N+1)=PMB(1,M,2)
C*****SHIFT METHOD OF CHARACTERISTICS DATA.
      CALL MCDATA(3,L1,L2,L3,KPTS)
   40 CONTINUE
C*****THE CALCULATION SEQUENCE IS NOW MODIFIED FOR SUBSEQUENT AXIS
C     AND FIELD POINT CALCULATIONS.
C
      DO 90 N=1,N2
      NI=N2+N
      L=N2+1-N
C*****LOAD DATA/ CALCULATE FIELD POINT/ STORE DATA.
      CALL MCDATA(1,L,L,L3,KPTS)
      CALL APS (GAMMA,P2,P3,NERROR)
      CALL MCDATA(2,L1,L2,L,KPTS)
      IF(N1-N1) 70,70,50
   50 NII=L-1
      LII=L
      DO 60 I=1,NII
C*****LOAD DATA/ CALCULATE FIELD POINT/ STORE DATA.
      CALL MCDATA(1,LII,LII-1,L3,KPTS)
      CALL FPS(GAMMA,P1,P2,P3,NERROR)
      CALL MCDATA(2,L1,L2,LII-1,KPTS)
   60 LII=LII-1
C*****STORE INITIAL CHARACTERISTICS DATA.
   70 DO 80 M=1,4
   80 CHARI(M,NI+1)=PMB(1,M,2)
C*****SHIFT METHOD OF CHARACTERISTICS DATA.
      CALL MCDATA(3,L1,L2,L3,L)
   90 CONTINUE
      RETURN
      END
      SUBROUTINE PMSBR(GAMMA,EMSTAR,PRATIO,BETA,XC,RC,K)
C
C*****THIS SUBROUTINE SUBDIVIDES THE INITIAL PRANDTL-MEYER EXPANSION
C     (WAVES OF FAMILY II) INTO APPROXIMATELY 1 DEGREE INCREMENTS.
C     INPUT DATA IS THEN CALCULATED FOR THE METHOD OF CHARACTERISTICS
C     NET AT THE POINT WHERE THE EXPANSION IS CENTERED.
C
C     SUBROUTINE REQUIRES---EMSPM.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     EMSTAR = APPROACH MACH STAR.
C     PRATIO = EXPANSION PRESSURE RATIO (P/PO).
C     BETA   = INITIAL FLOW ANGLE IN RADIANS.
C     XC     = LONGITUDINAL COORDINATE WHERE EXPANSION IS CENTERED.
C     RC     = RADIAL COORDINATE WHERE EXPANSION IS CENTERED.
```

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C      K       = NUMBER OF INCREMENTS OF THE TURNING ANGLE.
C      PMB     = A 3-DIMENSIONAL ARRAY, PMB(L,M,N), OF DATA FOR THE
C                METHOD OF CHARACTERISTICS NET.  THE SUBSCRIPTS L,M,N
C                HAVE THE FOLLOWING RANGES AND MEANINGS---
C                L=1,K+1 AND CORRESPONDS TO THE L-TH POINT OF THE
C                        SUBDIVIDED PRANDTL-MEYER EXPANSION.
C                M=1 CORRESPONDS TO X.
C                M=2 CORRESPONDS TO R.
C                M=3 CORRESPONDS TO MACH STAR (EMS).
C                M=4 CORRESPONDS TO THETA IN RADIANS (THETA).
C                N=1,2 CORRESPONDS TO THE PREVIOUS OR CURRENT I-CHAR.
C                L,N=1 AT POINT WHERE THE INITIAL FLOW CONDITIONS ARE
C                      SPECIFIED AND THE P-M EXPANSION IS CENTERED.
C
C
      DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
     1   P3(5)
      COMMON PMB, CHARI, CHARE, P1, P2, P3
      OMEGAF(A,B)=SQRT((B+1.0)/(B-1.0))*ATAN (SQRT((A**2-1.0)/
     1 ((B+1.0)/(B-1.0)-A**2)))-ATAN (SQRT(((B+1.0)/(B-1.0))*
     2 ((A**2-1.0)/((B+1.0)/(B-1.0)-A**2))))
      EMSPRF(A,B)=SQRT(((B+1.0)/(B-1.0))*(1.0-A**((B-1.0)/B)))
C
      EMS1=EMSTAR
      EMS2=EMSPRF(PRATIO,GAMMA)
C*****FOR WAVES OF FAMILY II.
      ANGLER=-(OMEGAF(EMS2,GAMMA) - OMEGAF(EMS1,GAMMA))
      IF (ANGLER)10,10,20
   10 K=(ABS (57.29578*ANGLER)+1.0)
      GO TO 30
   20 K = 1
   30 FK=K
      DELTA=ANGLER/FK
C*****KNOWN INITIAL INPUT DATA FOR PMB ARRAY.
      PMB(1,1,1)=XC
      PMB(1,2,1)=RC
      PMB(1,3,1)=EMS1
      PMB(1,4,1)=BETA
C*****CALCULATION OF ARRAY DATA FOR POINTS L=1,K+1 AND N=1.
      DO 1 L=1,K
      PMB(L+1,1,1)=PMB(L,1,1)
      PMB(L+1,2,1)=PMB(L,2,1)
      PMB(L+1,4,1)=PMB(L,4,1) + DELTA
    1 PMB(L+1,3,1)=EMSPM(EMS1,PMB(1,4,1),PMB(L+1,4,1),GAMMA)
      RETURN
      END
      FUNCTION EMSPM(EMSTAR,THETA1,THETA2,GAMMA)
C
C*****THIS FUNCTION CALCULATES THE FINAL MACH STAR AFTER A
C      PRANDTL-MEYER EXPANSION OR COMPRESSION GIVEN INITIAL M*
C      AND THE TURNING ANGLE IN RADIANS.
C
C      *** VARIABLES ***
C
C      EMSPM  = FINAL MACH STAR AFTER THE TURN OF (THETA2 - THETA1).
C      EMSTAR = APPROACH MACH STAR.
C      THETA1 = APPROACH FLOW ANGLE (IN RADIANS).
C      THETA2 = FINAL FLOW ANGLE (IN RADIANS).
C      GAMMA  = RATIO OF SPECIFIC HEATS.
C
C      THE SIGN CONVENTION FOR ANGLES IS CW(-) AND CCW(+).
C
C
```

```
      OMEGAF(A,B)=  SQRT((B+1.0)/(B-1.0))*ATAN (  SQRT((A**2-1.0)/
     1 ((B+1.0)/(B-1.0)-A**2)))-ATAN (  SQRT(((B+1.0)/(B-1.0))*
     2 ((A**2-1.0)/((B+1.0)/(B-1.0)-A**2))))
C*****SET INITIAL VALUES.
      NIT = 0
      NITMAX = 20
      NTYPE=1
C*****NTYPE=1, INTERVAL HALVE.  NTYPE=2, INTERPOLATE.
      RATIO=0.5
      ANGLE=(THETA2-THETA1)
      IF(ANGLE)  20,20,10
C*****FOR A REVERSIBLE COMPRESSION.
   10 EMSN=1.0
      OMEGAN=0.0
      EMSP=EMSTAR
      GO TO 30
C*****FOR A REVERSIBLE EXPANSION.
   20 EMSN=EMSTAR
      OMEGAN=OMEGAF(EMSN,GAMMA)
      EMSP=  SQRT((GAMMA+1.0)/(GAMMA-1.0))
C*****EVALUATE OMEGA FUNCTION FOR CONDITION *2*.
   30 OMEGA2=(OMEGAF(EMSTAR,GAMMA)-ANGLE)
C*****DOES THE SOLUTION EXIST.
      IF(OMEGA2)  40,60,70
   40 WRITE (3,50)
   50 FORMAT(//,10X,25H *** ERROR IN -EMSPM- ***  /)
      RETURN
   60 EMSPM=1.0
      RETURN
C*****INITIALLY INTERVAL HALVE AND THEN INTERPOLATE.
   70 NIT = NIT + 1
      IF(NIT .GT. NITMAX) GO TO 140
      EMST=EMSN+RATIO*(EMSP-EMSN)
      OMEGAT=OMEGAF(EMST,GAMMA)
      DIFFO=(OMEGAT-OMEGA2)/OMEGA2
      IF(ABS (DIFFO)-1.0E-4)  140,140,80
   80 IF(DIFFO)  90,140,100
   90 EMSN=EMST
      OMEGAN=OMEGAT
      GO TO 110
  100 EMSP=EMST
      OMEGAP=OMEGAT
      NTYPE=2
  110 DIFFMS = (EMSP-EMSN)/EMSN
      IF(ABS(DIFFMS) - 1.0E-4)  140,140,120
  120 GO TO (70,130), NTYPE
C*****INTERPOLATE FOR THE SOLUTION.
  130 RATIO=(OMEGA2-OMEGAN)/(OMEGAP-OMEGAN)
      GO TO 70
C*****SOLUTION FOUND.
  140 EMSPM=EMST
      IF(NIT .GT. NITMAX) WRITE (3,150) NIT,DIFFO
  150 FORMAT(/,5X,34H ***CONVERGENCE ERROR IN EMSPM, ( , I3, 2H , ,
     1   E10.3, 6H ) ***  /)
      RETURN
      END
      SUBROUTINE OUTBDY(N,NPRINT,BPTS)
C
C*****SUBROUTINE PRINTS THE CURRENT CALCULATED BOUNDARY POINT DATA.
C
C     ***VARIABLES***
C
C     N        = NUMBER OF CURRENT BOUNDARY POINT.
```

```
C       NPRINT = -1 OR 0, C.P.B. DATA NOT PRINTED.
C                +1, C.P.B. DATA PRINTED.
C       BPTS(M,N) = CURRENT BOUNDARY DATA.
C                   M=1 CORRESPONDS TO X.
C                   M=2 CORRESPONDS TO R.
C                   M=3 CORRESPONDS TO MACH STAR (EMS).
C                   M=4 CORRESPONDS TO THETA IN RADIANS (THETA).
C
C
        DIMENSION BPTS(5,30)
C
        IF(NPRINT) 2,2,1
    1   X=BPTS(1,N)
        R=BPTS(2,N)
        THETA=57.29578*BPTS(4,N)
C
        WRITE (3,10)          X, R, THETA
   10   FORMAT(F15.6, F29.6, F30.6)
C
    2   RETURN
        END
        SUBROUTINE MCDATA(NOP,L1,L2,L3,KPTS)
C
C*****SUBROUTINE LOADS, STORES, OR SHIFTS
C       METHOD OF CHARACTERISTICS DATA.
C
C       NOP =  1, LOADS PMB DATA IN P1,P2.
C           =  2, STORES P3 DATA IN PMB.
C           =  3, SHIFTS PMB DATA FROM I-2 TO I-1.
C
C
        DIMENSION PMB(100,5,2), CHARI(5,30), CHARE(5,30), P1(5), P2(5),
      1   P3(5)
        COMMON PMB, CHARI, CHARE, P1, P2, P3
C
        GO TO (10,30,50), NOP
C
   10   DO 20 M=1,4
        P1(M)=PMB(L1,M,2)
   20   P2(M)=PMB(L2,M,1)
        RETURN
C
   30   DO 40 M=1,4
   40   PMB(L3,M, 2)=P3(M)
        RETURN
C
   50   DO 70 KII=1,KPTS
        DO 60 M=1,4
   60   PMB(KII,M, 1)=PMB(KII,M, 2)
   70   CONTINUE
        RETURN
C
        END
        SUBROUTINE FPS(GAMMA,P1,P2,P3,NERROR)
C
C*****AXISYMMETRIC FIELD POINT SUBROUTINE  (FPS)
C
C       ***VARIABLES***
C
C       GAMMA  = RATIO OF SPECIFIC HEATS.
C       PI(J)  = J-TH FLOW VARIABLE AT THE POINT I WHERE I=1,2,OR 3.
C       P1(J) AND P2(J),J=1,4 = FLOW VARIABLES AT KNOWN POINTS 1 AND 2.
C       P3(J),J=1,4 = FLOW VARIABLES AT THE UNKNOWN POINT 3.
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C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C              J=1 CORRESPONDS TO X.
C              J=2 CORRESPONDS TO R.
C              J=3 CORRESPONDS TO MACH STAR (EMS).
C              J=4 CORRESPONDS TO THETA IN RADIANS (THET).
C     NERROR = -1, ERROR IN CALCULATION.
C            = 0, CALCULATION O.K.
C
C     POINTS 1 AND 3 ARE ASSUMED CONNECTED BY FAMILY I.
C     POINTS 2 AND 3 ARE ASSUMED CONNECTED BY FAMILY II.
C
C
      DIMENSION P1(5), P2(5), P3(5)
      ALPHAF(EMSTAR,GAMMA)=ATAN (SQRT((1.0 - ((GAMMA-1.0)/(GAMMA+1.0))
     1   *(EMSTAR**2))/(EMSTAR**2-1.0)))
      AVGF(A,B) = (A + B)/2.0
      PCOEFF(EMSTAR,ALPHA)=EMSTAR*TAN (ALPHA)
      QCOEFF(NPOINT,RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*
     1   (TAN (ALPHA)**2)*TAN (THETA))/(TAN (THETA) + ((-1.0)**NPOINT)*
     2   TAN (ALPHA))
      HQCOEF (RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*TAN (ALPHA)*
     1     SIN (ALPHA)*SIN (THETA))
C*****NPOINT IN  QCOEFF()  INDICATES THE KNOWN POINT BEING USED--1 OR 2.
C*****ERROR FLAG SET.
      NCOUNT=0
      NCTMAX=15
      NERROR=0
      EMSMAX=SQRT  ((GAMMA+1.0)/(GAMMA-1.0))
C*****KNOWN INPUT DATA FROM POINTS 1 AND 2.
      X1=P1(1)
      R1=P1(2)
      EMS1=P1(3)
      THET1=P1(4)
C
      X2=P2(1)
      R2=P2(2)
      EMS2=P2(3)
      THET2=P2(4)
C*****FOR INITIAL ESTIMATE OF AVERAGE VALUES BETWEEN POINTS 1-3 AND 2-3.
      R3=AVGF(R1,R2)
      EMS3=AVGF(EMS1,EMS2)
      THET3=AVGF(THET1,THET2)
      GO TO 11
C*****ITERATION FOR VARIABLES AT POINT 3.
    1 X3=(R2 - R1 + X1*TAN (DIFF13) - X2*TAN (SUM23))/
     1   (TAN (DIFF13) - TAN (SUM23))
      R3=(R1 + (X3 - X1)*TAN (DIFF13))
C*****TEST AND EVALUATION FOR HORIZONTAL I OR II CHARACTERISTICS.
      IF(ABS (DIFF13)-1.0E-3) 2,2,3
C*****FOR I HORIZONTAL.
    2 PROD13=HQCOEF (R13,EMS13,THET13,ALPH13)*(X3-X1)
      GO TO 4
    3 PROD13=QCOEFF(1,R13,EMS13,THET13,ALPH13)*(R3-R1)
    4 IF(ABS (SUM23)-1.0E-3) 5,5,6
C*****FOR II HORIZONTAL.
    5 PROD23=HQCOEF (R23,EMS23,THET23,ALPH23)*(X3-X2)
      GO TO 7
    6 PROD23=QCOEFF(2,R23,EMS23,THET23,ALPH23)*(R3-R2)
C*****CALCULATION OF FLOW VARIABLES AT POINT 3.
    7 THET3=(P13*THET1 + P23*THET2 + PROD13 - PROD23 + EMS1 - EMS2)/
     1   (P13+P23)
      EMS3=EMS1 - P13*(THET3-THET1) + PROD13
      DIFFMS = (EMS3-SAVE1)/SAVE1
```

```
      IF((EMS3.LT.1.0) .OR. (EMS3.GT.EMSMAX)) GO TO 13
      IF(ABS (DIFFMS) .LE. 1.0E-4) GO TO 12
C
   11 NCOUNT=NCOUNT+1
      IF(NCOUNT.GT.NCTMAX) GO TO 12
      SAVFI = EMS3
      R13=AVGF(R1,R3)
      R23=AVGF(R2,R3)
      EMS13=AVGF(EMS1,EMS3)
      EMS23=AVGF(EMS2,EMS3)
      THET13=AVGF(THET1,THET3)
      THET23=AVGF(THET2,THET3)
      ALPH13=ALPHAF(EMS13,GAMMA)
      ALPH23=ALPHAF(EMS23,GAMMA)
      P13=PCOEFF(EMS13,ALPH13)
      P23=PCOEFF(EMS23,ALPH23)
      DIFF13=THET13-ALPH13
      SUM23=THET23+ALPH23
      GO TO 1
C
   12 P3(1) = X3
      P3(2)=R3
      P3(3)=EMS3
      P3(4)=THET3
      IF(NCOUNT .GT. NCTMAX)  WRITE (3,920) NCOUNT,DIFFMS
  920 FORMAT(/, 5X,35H *** CONVERGENCE ERROR IN *FPS*, ( ,I3,2H , ,
     1   E10.3,6H ) ***  /)
      RETURN
C
   13 NERROR=-1
      WRITE (3,14)
   14 FORMAT(//,23X,29H *** ERROR IN *FPS* CALC. ***  //)
      RETURN
      END
      SUBROUTINE APS (GAMMA,P2,P3,NERROR)
C
C*****AXISYMMETRIC AXIS POINT SUBROUTINE (APS)
C
C     FOR THIS SUBROUTINE, THE UNKNOWN POINT 3 IS ON THE AXIS.
C     THE KNOWN POINT 2 AND THE UNKNOWN POINT 3 ARE ALONG FAMILY II.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     PI(J)  = J-TH FLOW VARIABLE AT THE POINT I WHERE I=1,2,OR 3.
C     P2(J),J=1,4 = FLOW VARIABLES AT KNOWN POINT 2.
C     P3(J),J=1,4 = FLOW VARIABLES AT THE UNKNOWN POINT 3.
C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C               J=1 CORRESPONDS TO X.
C               J=2 CORRESPONDS TO R.
C               J=3 CORRESPONDS TO MACH STAR (EMS).
C               J=4 CORRESPONDS TO THETA IN RADIANS (THET).
C     NERROR = -1, ERROR IN CALCULATION.
C            = 0, CALCULATION O.K.
C
C
      DIMENSION P2(5), P3(5)
      ALPHAF(EMSTAR,GAMMA)=ATAN (SQRT((1.0 - ((GAMMA-1.0)/(GAMMA+1.0))
     1   *(EMSTAR**2))/(EMSTAR**2-1.0)))
      AVGF(A,B) = (A + B)/2.0
      PCOEFF(EMSTAR,ALPHA)=EMSTAR*TAN (ALPHA)
      QCOEFF(NPOINT,RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*
     1   (TAN (ALPHA)**2)*TAN (THETA))/(TAN (THETA) + ((-1.0)**NPOINT)*
```

```
     2   TAN (ALPHA))
C*****NPOINT IN  QCOEFF()  INDICATES THE KNOWN POINT BEING USED--1 OR 2.
C*****ERROR FLAG SET.
      NCOUNT = 0
      NCTMAX=15
      NERROR=0
      EMSMAX=SQRT  ((GAMMA+1.0)/(GAMMA-1.0))
C*****KNOWN INPUT DATA FOR POINTS 2 AND 3.
      X2=P2(1)
      R2=P2(2)
      EMS2=P2(3)
      THET2=P2(4)
      R3=0.0
      THET3=0.0
C*****FOR INITIAL ESTIMATE OF AVERAGE VALUES BETWEEN POINTS 2 AND 3.
      EMS3=EMS2
      R23=AVGF(R2,R3)
      THET23=AVGF(THET2,THET3)
      GO TO 5
C*****ITERATION FOR VARIABLES AT POINT 3.
    1 X3=X2 - (R2/TAN (SUM23))
      EMS3=EMS2 - P23*THET2 - Q23*R2
      DIFFMS = (EMS3-SAVE1)/SAVE1
      IF((EMS3.LT.1.0) .OR. (EMS3.GT.EMSMAX))  GO TO 7
      IF(ABS(DIFFMS) .LE. 1.0E-4)  GO TO 6
C
    5 NCOUNT=NCOUNT+1
      IF(NCOUNT.GT.NCTMAX) GO TO 6
      SAVE1=EMS3
      EMS23=AVGF(EMS2,EMS3)
      ALPH23=ALPHAF(EMS23,GAMMA)
      SUM23=THET23+ALPH23
      P23=PCOEFF(EMS23,ALPH23)
      Q23=QCOEFF(2,R23,EMS23,THET23,ALPH23)
      GO TO 1
C
    6 P3(1)=X3
      P3(2)=R3
      P3(3)=EMS3
      P3(4)=THET3
      IF(NCOUNT .GT. NCTMAX)  WRITE (3,60) NCOUNT,DIFFMS
   60 FORMAT(/, 5X,35H *** CONVERGENCE ERROR IN *APS*, ( ,I3,2H , ,
     1   E10.3,6H ) ***  /)
      RETURN
C
    7 NERROR=-1
      WRITE (3,8)
    8 FORMAT(//,23X,29H *** ERROR IN *APS* CALC. ***  //)
      RETURN
      END
      SUBROUTINE CPBS(GAMMA, P1, P2, P3, NERROR)
C
C*****AXISYMMETRIC CONSTANT PRESSURE BOUNDARY SUBROUTINE (CPBS)
C
C     POINTS 2 AND 3 ARE ON THE SAME CONSTANT PRESSURE BOUNDARY.
C     POINTS 1 AND 3 ARE ASSUMED CONNECTED BY FAMILY 1.
C
C     ***VARIABLES***
C
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     PI(J)  = J-TH FLOW VARIABLE AT THE POINT I WHERE I=1,2,OR 3.
C     P1(J) AND P2(J),J=1,4 = FLOW VARIABLES AT KNOWN POINTS 1 AND 2.
C     P3(J),J=1,4 = FLOW VARIABLES AT THE UNKNOWN POINT 3.
```

```
C     THE J SUBSCRIPT INDICATES THE FOLLOWING VARIABLES---
C              J=1 CORRESPONDS TO X.
C              J=2 CORRESPONDS TO R.
C              J=3 CORRESPONDS TO MACH STAR (EMS).
C              J=4 CORRESPONDS TO THETA IN RADIANS (THET).
C     NERROR = -1, ERROR IN CALCULATION.
C            = 0, CALCULATION O.K.
C
C
      DIMENSION P1(5), P2(5), P3(5)
      ALPHAF(EMSTAR,GAMMA)=ATAN (SQRT((1.0 - ((GAMMA-1.0)/(GAMMA+1.0))
     1   *(EMSTAR**2))/(EMSTAR**2-1.0)))
      AVGF(A,B) = (A + B)/2.0
      PCOEFF(EMSTAR,ALPHA)=EMSTAR*TAN (ALPHA)
      HOCOEF (RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*TAN (ALPHA)*
     1    SIN (ALPHA)*SIN (THETA))
      QCOEFF(NPOINT,RADIUS,EMSTAR,THETA,ALPHA)=((EMSTAR/RADIUS)*
     1   (TAN (ALPHA)**2)*TAN (THETA))/(TAN (THETA) + ((-1.0)**NPOINT)*
     2   TAN (ALPHA))
C*****NPOINT IN  QCOEFF()  INDICATES THE KNOWN POINT BEING USED--1 OR 2.
C*****ERROR FLAG SET.
      NCOUNT=0
      NCTMAX=15
      NERROR=0
C*****KNOWN INPUT DATA FROM POINTS 1 AND 2.
      X1=P1(1)
      R1=P1(2)
      EMS1=P1(3)
      THET1=P1(4)
C
      X2=P2(1)
      R2=P2(2)
      EMS2=P2(3)
      THET2=P2(4)
C*****FOR INITIAL ESTIMATE OF AVERAGE VALUES BETWEEN POINTS 1-3 AND 2-3.
      R3=AVGF(R1,R2)
      THET3=AVGF(THET1,THET2)
C*****SINCE POINTS 2 AND 3 ARE ON THE SAME CONSTANT PRESSURE BOUNDARY,
      EMS3=EMS2
      EMS13=AVGF(EMS1,EMS3)
      ALPH13=ALPHAF(EMS13,GAMMA)
      P13=PCOEFF(EMS13,ALPH13)
      GO TO 6
C*****ITERATION FOR VARIABLES AT POINT 3.
    1 X3=(R1 - R2 + X2*TAN (THET23) - X1*TAN (DIFF13))/
     1   (TAN (THET23) - TAN (DIFF13))
      R3=(R1 + (X3 - X1)*TAN (DIFF13))
      SIGN = R3*SAVE1
C*****IF SIGN IS NEGATIVE OR ZERO, AN ERROR HAS OCCURRED.
      IF(SIGN) 8,8,2
C*****TEST AND EVALUATION FOR HORIZONTAL I-CHARACTERISTIC.
C*****FOR I HORIZONTAL.
    2 IF(ABS (DIFF13)-1.0E-3) 3,3,4
    3 PROD13=HOCOEF (R13,EMS13,THET13,ALPH13)*(X3-X1)
      GO TO 5
    4 PROD13=QCOEFF(1,R13,EMS13,THET13,ALPH13)*(R3-R1)
    5 THET3=(THET1 - ((EMS3-EMS1-PROD13)/P13))
      DIFFT=(THET3-SAVE2)/SAVE2
      IF(ABS(DIFFT) .LE. 1.0E-4)  GO TO 7
C
    6 NCOUNT=NCOUNT+1
      IF(NCOUNT.GT.NCTMAX) GO TO 7
      SAVE1=R3
```

```
      SAVE2=THET3
      R13=AVGF(R1,R3)
      THET13=AVGF(THET1,THET3)
      DIFF13=THET13-ALPH13
      Q13=QCOEFF(1,R13,EMS13,THET13,ALPH13)
      THET23=AVGF(THET2,THET3)
      GO TO 1
C
    7 P3(1)=X3
      P3(2)=R3
      P3(3)=EMS3
      P3(4)=THET3
      IF(NCOUNT .GT. NCTMAX)  WRITE (3,70) NCOUNT,DIFFT
   70 FORMAT(/, 5X,36H *** CONVERGENCE ERROR IN *CPBS*, ( ,I3,2H , ,
     1   E10.3,6H ) ***  /)
      RETURN
C
    8 NERROR=-1
      WRITE (3,9)
    9 FORMAT(//,23X,30H *** ERROR IN *CPBS* CALC. ***  //)
      RETURN
      END
      SUBROUTINE OUTPUT(GAMMA,EMS1,PRATIO,BETA,NPRINT,NFLOW)
C
C*****SUBROUTINE PRINTS INPUT AND SOME OUTPUT DATA, AND COL. HEADINGS
C     FOR THE AXISYMMETRIC CONSTANT PRESSURE BOUNDARY SUBPROGRAM.
C
      EMNPRF(PR,GAMMA)=SQRT((2.0/(GAMMA-1.0))*
     1                 (PR**(-(GAMMA-1.0)/GAMMA)-1.0))
      EMSMNF(EMN,GAMMA)=SQRT((0.5*(GAMMA+1.0)*(EMN**2))/
     1                 (1.0+0.5*(GAMMA-1.0)*(EMN**2))  )
      EMNMSF(EMS,GAMMA)=SQRT(((2.0*(EMS**2))/(GAMMA+1.0))/
     1                 (1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))  )
C
      IF(NPRINT) 70,70,10
   10 BETAD=57.2957795*BETA
      EMN1 = EMNMSF(EMS1,GAMMA)
      EMN2=EMNPRF(PRATIO,GAMMA)
      EMS2=EMSMNF(EMN2,GAMMA)
      GO TO (20,50), NFLOW
C
   20 IF(ABS (BETA)-1.0E-4) 30,30,40
C
   30 WRITE (3,100)            GAMMA, BETAD, EMN1, PRATIO,
     1                         PRATIO, EMN2, EMS2
  100 FORMAT(1H1, ///, 21X, 31H CONSTANT PRESSURE JET BOUNDARY /,
     1 19X, 36H FOR INITIALLY UNIFORM AXI-SYMMETRIC /,
     2 24X, 25H SUPERSONIC INTERNAL FLOW //,
     3 28X, 17H ***INPUT DATA*** //,
     4 7X, 9H GAMMA = F5.3, 24X, 15H BETA (DEG.) = F10.6 //,
     5 7X, 12H MACH NO. = F9.6, 17X, 8H P/PO = F8.6 //,
     6 22X, 27H ***BOUNDARY OUTPUT DATA*** //,
     7 7X,8H P/PO = F8.6,3X,11H MACH NO. =F9.6,3X,12H MACH STAR =F9.6//,
     8 7X, 2H X, 27X, 2H R, 23X, 13H THETA (DEG.) /)
C
      GO TO 70
C
   40 WRITE (3,101)            GAMMA, BETAD, EMN1, PRATIO,
     1                         PRATIO, EMN2, EMS2
  101 FORMAT(1H1, ///, 21X, 31H CONSTANT PRESSURE JET BOUNDARY /,
     1 19X, 36H FOR INITIALLY CONICAL AXI-SYMMETRIC /,
     2 24X, 25H SUPERSONIC INTERNAL FLOW //,
     3 28X, 17H ***INPUT DATA*** //,
```

```
     4 7X, 9H GAMMA = F5.3, 24X, 15H BETA (DEG.) = F10.6 //,
     5 7X, 12H MACH NO. = F9.6, 17X, 8H P/PO = F8.6 //,
     6 22X, 27H ***BOUNDARY OUTPUT DATA*** //,
     7 7X,8H P/PO = F8.6,3X,11H MACH NO. =F9.6,3X,12H MACH STAR =F9.6//,
     8 7X, 2H X, 27X, 2H R, 23X, 13H THETA (DEG.) /)
C
      GO TO 70
C
   50 WRITE (3,102)           GAMMA, BETAD, EMN1, PRATIO,
     1                        PRATIO, EMN2, EMS2
  102 FORMAT(1H1, ///, 21X, 31H CONSTANT PRESSURE JET BOUNDARY /,
     1 19X, 36H FOR INITIALLY UNIFORM AXI-SYMMETRIC /,
     2 24X, 25H SUPERSONIC EXTERNAL FLOW //,
     3 28X, 17H ***INPUT DATA*** //,
     4 7X, 9H GAMMA = F5.3, 24X, 15H BETA (DEG.) = F10.6 //,
     5 7X, 12H MACH NO. = F9.6, 17X, 8H P/PO = F8.6 //,
     6 22X, 27H ***BOUNDARY OUTPUT DATA*** //,
     7 7X,8H P/PO = F8.6,3X,11H MACH NO. =F9.6,3X,12H MACH STAR =F9.6//,
     8 7X, 2H X, 27X, 2H R, 23X, 13H THETA (DEG.) /)
C
   70 RETURN
      END
      SUBROUTINE TEST(RLMT,NSTMT,NFLOW,N,BPTS)
C
C*****SUBROUTINE STOPS CALCULATIONS AND RETURNS TO THE MASTER IF ---
C        1. THE INTERNAL BOUNDARY RADIUS EXCEEDS RLMT OR IF THE JET
C           BOUNDARY ANGLE CHANGES SIGN.
C        2. THE EXTERNAL BOUNDARY RADIUS IS LESS THAN RLMT.
C
      DIMENSION BPTS(5,30)
C
      GO TO (10,30), NFLOW
C
   10 IF(BPTS(2,N)-RLMT) 20,50,50
C
   20 IF(BPTS(4,N-1)*BPTS(4,N)) 50,50,40
C
   30 IF(BPTS(2,N)-RLMT) 50,50,40
C
   40 NSTMT=1
      GO TO 60
C
   50 NSTMT=2
   60 RETURN
      END
       SUBROUTINE SLIP(EMS1,THETA1,GAMMA1,EMS2,THETA2,GAMMA2,
     1 THETAS,NSTOP)
C
C     THIS SUBROUTINE CALCULATES THE SLIPLINE ANGLE FOR THE
C     OBLIQUE SHOCK RECOMPRESSION SYSTEM WHICH OCCURS AT THE
C     IMPINGMENT POINT OF TWO SUPERSONIC STREAMS IF IT EXISTS.
C     ONE OF THE SHOCKS MAY BE A STRONG SHOCK.
C
C     SUBOUTINE REQUIRED----STSHK
C
C     ****VARIABLES****
C
C     EMS1   = MACH STAR OF STREAM 1.
C     THETA1 = FLOW ANGLE OF STREAM 1.
C     GAMMA1 = RATIO OF SPECIFIC HEATS FOR STREAM 1.
C     DELT1  = SHOCK TURNING ANGLE FOR STREAM 1.
C     DDELT1 = TURNING ANGLE DERIVATIVE OF STREAM 1.
C     EMS2   = MACH STAR OF STREAM 2.
```

```
C      THETA2 = FLOW ANGLE OF STREAM 2.
C      GAMMA2 = RATIO OF SPECIFIC HEATS FOR STREAM 2.
C      DELT2  = SHOCK TURNING ANGLE FOR STREAM 2.
C      DDELT2 = TURNING ANGLE DERIVATIVE OF STREAM 2.
C      THETAS = SLIPLINE ANGLE
C      NSTOP  = 1, FOR A SOLUTION
C             = 3, FOR NO SOLUTION
C
C      NOTE THAT THETA1 IS ASSUMED LARGER THAN THETA2.
C
       EMNMSF(EMS,GAMMA)=SQRT((2.0/(GAMMA+1.0))*(EMS**2)/
      1(1.0-((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2)))
C
C      CALCULATION OF THE MAXIMUM TURNING ANGLE FOR A GIVEN
C      APPROACH MACH NUMBER AND GAMMA; NACA R-1135,EQ.168.
C
       SINWA2(EMN,GAMMA)=(0.25/(GAMMA*(EMN**2)))*((GAMMA+1.0)*
      1(EMN**2)-4.0+SQRT((GAMMA+1.0)*((GAMMA+1.0)*(EMN**4)+8.0*
      2(GAMMA-1.0)*(EMN**2)+16.0)))
C
C      SINWA2 CALCULATES THE SINE OF THE SHOCK WAVE ANGLE SQUARED
C      FOR MAXIMUM STREAM DEFLECTION BEHIND THE SHOCK (EQN 168)
C
       DELTAM(EMN,GAMMA,SIN2WA)=ATAN ((2.0*SQRT((1.0-SIN2WA)/SIN2WA)
      1*((EMN**2)*SIN2WA-1.0))/(2.0+(EMN**2)*(GAMMA+1.0-2.0*SIN2WA)))
C
C      DELTAM CALCULATES THE MAXIMUM TURNING ANGLE GIVEN THE
C      APPROACH MACH NUMBER GAMMA AND THE SINE SQUARED OF THE WAVE
C      ANGLE,SIN2WA,FOR THE MAXIMUM DEFLECTION (EQN 139A).
C
       PROSHK(EMN,SIN2WA,GAMMA)=(2.0*GAMMA*(EMN**2)*SIN2WA-GAMMA
      1 +1.0)/(GAMMA+1.0)
C
C      PROSHK CALCULATES THE STATIC PRESSURE RISE FOR AN OBLIQUE
C      SHOCK GIVEN THE APPROACH MACH NUMBER, THE SINE SQUARED OF
C      THE WAVE ANGLE AND GAMMA (EQN 128)
C
       NIT=0
       NITMAX = 15
       EMN1=EMNMSF(EMS1,GAMMA1)
       DELT1M=DELTAM(EMN1,GAMMA1,SINWA2(EMN1,GAMMA1))
       PRMAX1= PROSHK(EMN1,SINWA2(EMN1,GAMMA1),GAMMA1)
       EMN2 = EMNMSF(EMS2,GAMMA2)
       DELT2M = DELTAM(EMN2,GAMMA2,SINWA2(EMN2,GAMMA2))
       PRMAX2 = PROSHK(EMN2,SINWA2(EMN2,GAMMA2),GAMMA2)
       IF((THETA1-THETA2) .GT. (DELT1M+DELT2M)) GO TO 600
C
C      DETERMINE WHICH STREAM IS THE WEAK STREAM
C
       IF(PRMAX1 - PRMAX2)100,100,110
C
C      STREAM 1 IS THE WEAK STREAM
C
  100  PRSSA = PRMAX1
       PR1   = PRSSA
       DEL1  = DELT1M
       PRNS  = (2.0*GAMMA1*EMN1**2 - GAMMA1 + 1.0)/(GAMMA1+1.0)
       GO TO 120
C       STREAM  2 IS THE WEAKER STREAM
C
  110  PRSSA = PRMAX2
       PR1   = PRSSA
       DEL1  = DELT2M
```

```
      PRNS  = (2.0*GAMMA2*EMN2**2-GAMMA2+1.0)/(GAMMA2+1.0)
C
C      CALCULATE THE MAXIMUM TOTAL STREAM TURNING ANGLE BY A
C      NUMERICAL INTERACTION PROCEDURE
C
 120  ICOUNT = 1
      CALL STSHK(PRSSA,EMN1,GAMMA1,DELT1,DDELT1)
      CALL STSHK(PRSSA,EMN2,GAMMA2,DELT2,DDELT2)
      DELTA = DELT1 + DELT2
      DTHETA = THETA1 - THETA2
      DDLTTA = DDELT1 + DDELT2
      F1DDEL = DDLTTA
      PRSSB = PRSSA + (PRNS - PRSSA)/2.0
      IF (DTHETA - DELTA) 220,160,130
C
C      WHEN SHOCK TURNING ANGLES FOR MAX. DEFLECTION OF THE WEAK
C      STREAM ARE: (A) GREATER THAN THE STRAMLINE ANGLES A WEAK
C      SHOCK SOLUTION EXISTS; (B) LESS THAN THE STREAMLINE ANGLES
C      A STRONG SOLUTION SOUGHT.
C
 130  ICOUNT =ICOUNT + 1
      CALL STSHK(PRSSB,EMN1,GAMMA1,DELT1,DDELT1)
      CALL STSHK(PRSSB,EMN2,GAMMA2,DELT2,DDELT2)
      F2DDEL = DDELT1 + DDELT2
      IF (ABS(F2DDEL) -1.0E-5) 150,150,140
 140  PRSSC = PRSSB-F2DDEL*(PRSSB-PRSSA)/(F2DDEL-F1DDEL)
      PRSSA = PRSSB
      PRSSB = PRSSC
      F1DDEL= F2DDEL
      IF(ICOUNT -15) 130,130,170
 150  DELMAX = DELT1 + DELT2
C
C      THIS COMPLETES THE INTERACTION LOOP TO DETERMINE THE MAXIMUM
C      TURNING CAPABILITY OF THE TWO STREASMS.
C
      IF(DELMAX-DTHETA)600,160,200
 160  THETAS = THETA1 - DELT1
      NSTOP  = 1
      RETURN
C
C
 170  WRITE(3,500)ICOUNT,F2DDEL,PRSSB
 500  FORMAT('1',5X,'***CONVERGENCE ERROR IN SLIP,LOOP1    ('I3,
     1 5X,F10.6,5X,F10.6, ' ) ***')
      IF((DELT1 + DELT2 ) - DTHETA) 600,160,200
C
C      BEGIN ITERATION LOOP FOR SLIP LINE ANGLE
C
 200  NIT = 1
      IF(ABS(DDELT1+DDELT2) .LE. 1.0E-6) GO TO 160
      IF (DELTA - DTHETA) 210,210,220
 210  F1DEL = DELTA - DTHETA
      PR2 = PR1 -F1DEL/DDLTTA
      GO TO 230
 220  NIT = 1
      PR1 = 1.0 + DTHETA*(PR1-1.0)/DELTA
      CALL STSHK(PR1,EMN1,GAMMA1,DELT1,DDELT1)
      CALL STSHK(PR1,EMN2,GAMMA2,DELT2,DDELT2)
      IF(ABS(DDELT1+DDELT2) .LE. 1.0E-6) GO TO 160
      F1DEL = DELT1 + DELT2 - DTHETA
      PR2 = PR1 - F1DEL/(DDELT1 + DDELT2)
 230  NIT = NIT + 1
      CALL STSHK(PR2,EMN1,GAMMA1,DELT1,DDELT1)
```

```
      CALL STSHK(PR2,EMN2,GAMMA2,DELT2,DDELT2)
      IF(ABS(DDELT1+DDELT2) .LE. 1.0E-6) GO TO 160
      F2DEL = DELT1 + DELT2 - DTHETA
      IF(ABS(F2DEL) - 1.0E-5)250,250,240
  240 PR2 = PR2-F2DEL/(DDELT1 + DDELT2)
      IF(NIT - NITMAX)230,230,260
  250 THETAS = THETA1 - DELT1
      NSTOP = 1
      RETURN
C
C
  260 THETAS = THETA1 - DELT1
      NSTOP = 1
      WRITE(3,510) NIT,F2DEL,PR2
  510 FORMAT('1',5X,'***CONVERGENCE ERROR IN SLIP,  (',I3, 2(5X,F10.6
     1 ) , '  )***')
      RETURN
C
  600 NSTOP = 3
      WRITE(3,700)
  700 FORMAT(15X,48H ***SOLUTION FOR SLIPLINE ANGLE DOESN'T EXIST***
     1 //)
      RETURN
      END
      SUBROUTINE STSHK(PRSS,EMN,GAMMA,DELT,DDELT)
C
C     THIS SUBROUTINE CALCULATES THE OBLIQUE TURNING ANGLE AND
C     ITS DERIVATIVE AS A FUNCTION OF THE PRESSURE RATIO
C     ACCROSS THE SHOCK.
C
C     PRSS  = PRESURE RATIO ACROSS THE SHOCK.
C     EMN   = MACH NUMBER UPSTREAM OF THE SHOCK.
C     GAMMA = RATIO OF THE SPECIFIC HEATS.
C     DELT  = STREAMLINE TURNING ANGLE.
C     DDELT = DERIVATIVE OF THE TURNING ANGLE
C
      A=(2.0*GAMMA*EMN**2-GAMMA+1.0-(GAMMA +1.0)*PRSS)/((GAMMA
     1 +1.0)*PRSS+ GAMMA - 1.0)
      B=((PRSS - 1.0)/(GAMMA*EMN**2-PRSS +1.0))*SQRT(A)
      DELT = ATAN(B)
C
C     COMPUTATION OF THE DERIVATIVE
C
      C=A/(GAMMA*EMN**2-PRSS+1.0) - (GAMMA + 1.0)*(PRSS-1.0)/(((
     1 GAMMA +1.0)*PRSS + GAMMA - 1.0)**2)
      DDELT = (1.0/(1.0+B**2)) * ((GAMMA*EMN**2)/(GAMMA*EMN**2
     1 -PRSS+1.0))*(1.0/SQRT(A))*C
      RETURN
      END
      FUNCTION PRSHK(EMSTAR, DELTA, GAMMA)
C
C*****OBLIQUE SHOCK FUNCTION (REFERENCE NACA R-1135)
C
C     THIS FUNCTION CALCULATES THE STATIC PRESSURE RATIO ACROSS AN
C     OBLIQUE SHOCK (WEAK SOLUTION) GIVEN THE APPROACH MACH STAR AND
C     THE TURNING ANGLE (IN RADIANS).
C
C     ***VARIABLES***
C
C     EMSTAR = APPROACH MACH STAR (M* = V/C*).
C     DELTA  = TURNIRG ANGLE (IN RADIANS).
C     GAMMA  = RATIO OF SPECIFIC HEATS.
C     PRSHK  = FINAL TO APPROACH STATIC PRESSURE RATIO.
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```
C
C
      DIMENSION   Y(3)
C*****EQUATION COEFFICIENT FUNCTIONS.
      CONSTB (EMSQD,DELTA,GAMMA) = -(EMSQD + 2.0)/EMSQD -
     1   GAMMA*(SIN (DELTA)**2)
      CONSTC (EMSQD,DELTA,GAMMA) = (2.0*EMSQD + 1.0)/(EMSQD**2) +
     1  (((GAMMA + 1.0)**2)/4.0 + (GAMMA - 1.0)/EMSQD)*(SIN (DELTA)**2)
      CONSTD (EMSQD,DELTA) = -(COS (DELTA)**2)/(EMSQD**2)
      EMNSQD (EMS,GAMMA)=(2.0/(GAMMA+1.0))*(EMS**2)/(1.0
     1   -((GAMMA-1.0)/(GAMMA+1.0))*(EMS**2))
C
      EM2=EMNSQD (EMSTAR,GAMMA)
C*****SOLUTION OF CUBIC EQUATION FOR WAVE ANGLE SQUARED.
      A = (1.0/3.0)*(3.0*CONSTC (EM2,DELTA,GAMMA) -
     1  (CONSTB (EM2,DELTA,GAMMA))**2)
      B = (1.0/27.0)*(2.0*(CONSTB (EM2,DELTA,GAMMA)**3) -
     1  9.0*(CONSTB (EM2,DELTA,GAMMA))*(CONSTC (EM2,DELTA,GAMMA)) +
     2  27.0*CONSTD (EM2,DELTA))
      COSPHI = ( -B/2.0)/SQRT( -(A**3)/27.0)
      IF(ABS (COSPHI) - 1.0) 20,20,10
   10 PRSHK = 0.0
      RETURN
C
   20 PHI = (ATAN (SQRT(1.0 - COSPHI**2)/COSPHI))
      IF (PHI) 1,2,2
    1 PHI = PHI + 3.141593
    2 DO 3 I=1,3
      AI = I
C*****Y(I) IS THE SINE SQUARED OF THE WAVE ANGLE.
    3 Y(I) = 2.0*SQRT(-A/3.0)*COS (PHI/3.0 + (AI-1.0)*2.094395) -
     1        CONSTB (EM2,DELTA,GAMMA)/3.0
C*****THE ROOTS OF THE CUBIC EQN WILL NOW BE ARRANGED IN ASCENDING
C     ORDER, THAT IS, Y(1)  LESS THAN Y(2) LESS THAN Y(3).
C
      DO 6 I=1,2
      N = I + 1
      DO 5 J=N,3
      IF(Y(I)-Y(J)) 5,5,4
    4 SAVE = Y(J)
      Y(J) = Y(I)
      Y(I) = SAVE
    5 CONTINUE
    6 CONTINUE
C*****THE ROOT CORRESPONDING TO THE WEAK SOLUTION IS Y(2) AND
C     THE ROOT CORRESPONDING TO THE STRONG SOLUTION IS Y(3).
C     Y(I) IS THE SQUARE OF THE SINE OF THE SHOCK ANGLE (SIGMA).
C
      I = 2
      PRSHK = (2.0*GAMMA*EM2*Y(I) - (GAMMA - 1.0))/(GAMMA + 1.0)
      RETURN
      END
      SUBROUTINE TEGRAL(PHID,CSQD,TRBU,EI1J,EI1D,EI3J,EI3D,ETAJ,
     1                  PHIJ,EI2J)
C
C*****THIS SUBROUTINE CALCULATES THE TURBULENT JET MIXING INTEGRALS.
C
C     ***VARIABLES***
C
C     PHID = DISCRIMINATING STREAMLINE VELOCITY RATIO.
C     CSQD = FREE-STREAM CROCCO NUMBER SQUARED.
C     TRBU = BASE TO FREE-STREAM STAGNATION TEMPERATURE RATIO.
C     EI1J = MIXING INTEGRAL 1 FOR  J  STREAMLINE.
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C      EI1D = MIXING INTEGRAL 1 FOR  D  STREAMLINE.
C      EI3J = MIXING INTEGRAL 3 FOR  J  STREAMLINE.
C      EI3D = MIXING INTEGRAL 3 FOR  D  STREAMLINE.
C      PHI1 = DUMMY VARIABLE FOR THE FUNCTION STATEMENTS.
C      TRO1 = DUMMY VARIABLE FOR THE FUNCTION STATEMENTS.
C
C
       DIMENSION  TRO(350),EI1(350),EI2(350),EI3(350)
       COMMON  /ERFVP/ PHI(350)
       TJM1F(PHI1,CSQD,TRO1) = PHI1/(TRO1-CSQD*(PHI1**2))
       TJM2F(PHI1,CSQD,TRO1) = (PHI1**2)/(TRO1-CSQD*(PHI1**2))
       TJM3F(PHI1,CSQD,TRO1) = (PHI1*TRO1)/(TRO1-CSQD*(PHI1**2))
C*****THE ERROR FUNCTION VELOCITY PROFILE, PHI(I), IS INITIALIZED IN
C      *BLOCK DATA* AND STORED IN LABELED COMMON *ERFVP*.  PHI(I) IS
C      GIVEN FOR I=1,350 VALUES OF ETA IN THE RANGE OF ETA=-3.5 TO
C      ETA=3.5 IN INCREMENTS OF DETA=0.02.
C*****INCREMENT SIZE AND INITIAL VALUES AT (ETA RB) ARE SPECIFIED HERE.
       EPS=EI1D
       DETA = 0.02
       TRO(1) = TRBO
       EI1(1) = 0.0
       EI2(1) = 0.0
       EI3(1) = 0.0
C*****CALCULATION OF THE MIXING TABLE BY THE TRAPEZOIDAL RULE.
       DO 2 I=1,349
       TRO(I+1) = (TRBO + (1.0-TRBO)*PHI(I+1))
       EI1(I+1) = EI1(I) + 0.5*(TJM1F(PHI(I+1),CSQD,TRO(I+1)) +
      1            TJM1F(PHI(I),CSQD,TRO(I)))*DETA
       EI2(I+1) = EI2(I) + 0.5*(TJM2F(PHI(I+1),CSQD,TRO(I+1)) +
      1            TJM2F(PHI(I),CSQD,TRO(I)))*DETA
       EI3(I+1) = EI3(I) + 0.5*(TJM3F(PHI(I+1),CSQD,TRO(I+1)) +
      1            TJM3F(PHI(I),CSQD,TRO(I)))*DETA
       J = I+1
       IF(PHI(J) .LT. (0.25)) GO TO 2
       IF(ABS(1.0-((EI1(J)-EI2(J))/(EI1(I)-EI2(I)))).LE.1.0E-04) GO TO 3
     2 CONTINUE
C*****DETERMINE THE J- AND D-STREAMLINE VALUES OF THE INTEGRALS.
     3 EI1J = EI1(J) - EI2(J)
C*****TABLE SEARCH AND INTERPOLATION FOR EI3J.
       DO 4 I=1,J
       IF(EI1(I) .GT. EI1J)  GO TO 5
     4 CONTINUE
     5 EI3J = EI3(I-1) + ((EI3(I)-EI3(I-1))/(EI1(I)-EI1(I-1)))*
      1        (EI1J-EI1(I-1))
       EI2J = EI2(I-1) + ((EI2(I)-EI2(I-1))/(EI1(I)-EI1(I-1)))*
      1        (EI1J-EI1(I-1))
       PHIJ=PHI(I-1) +((PHI(I)-PHI(I-1))/(EI1(I)-EI1(I-1)))*
      1     (EI1J-EI1(I-1))
       ETAJ=FLOAT(I-2) * DETA+(DETA/(EI1(I)-EI1(I-1)))*
      1     (EI1J-EI1(I-1))-3.5
C*****TABLE SEARCH AND INTERPOLATION FOR EI1D, EI3D.
       DO 6 I=1,J
       IF(PHI(I) .GT. PHID)  GO TO 7
     6 CONTINUE
     7 EI1D = EI1(I-1) + ((EI1(I)-EI1(I-1))/(PHI(I)-PHI(I-1)))*
      1        (PHID-PHI(I-1))
       EI3D = EI3(I-1) + ((EI3(I)-EI3(I-1))/(PHI(I)-PHI(I-1)))*
      1        (PHID-PHI(I-1))
       IF (ABS(EPS).LT.1.E-5) RETURN
       EI1D=EI1D-EPS
       IF (EI1D) 8,8,9 .
     8 EI1D=0.
       PHID=1.E-6
```

```
      RETURN
    9 DO 10 I=1,J
      IF (EI1(I).GT.EI1D) GOTO 11
   10 CONTINUE
   11 PHID=PHI(I-1) + ((PHI(I)-PHI(I-1))/(EI1(I)-EI1(I-1)))*
     1     (EI1D-EI1(I-1))
      RETURN
      END
      SUBROUTINE TEGDSL(PHID,CSQD,TRBO,EI1D,EI3D)
C
C*****THIS SUBROUTINE CALCULATES THE TURBULENT JET MIXING INTEGRALS
C     WHEN PHI-D IS DEFINED BY THE ONERA RECOMPRESSION CRITERIA
C
C     ***VARIABLES***
C
C     PHID=DISCRIMINATING STREAMLINE VELOCITY RATIO.
C     CSQD=FREE-STREAM CRUCCO NUMBER SQUARED.
C     TRBO=BASE TO FREE-STREAM STAGNATION TEMPERATURE RATIO.
C     EI1J=MIXING INTEGRAL 1 FOR J STREAMLINE.
C     EI1D=MIXING INTEGRAL 1 FOR D STREAMLINE.
C     EI3J=MIXING INTEGRAL 3 FOR J STREAMLINE.
C     EI3D=MIXING INTEGRAL 3 FOR D STREAMLINE.
C     PHI1=DUMMY VARIABLE FOR THE FUNCTION STATEMENTS.
C     TRO1=DUMMY VARIABLE FOR THE FUNCTION STATEMENTS.
C
C
      DIMENSION  TRO(350),EI1(350),EI3(350)
      COMMON  /ERFVP/ PHI(350)
      TJM1F(PHI1,CSQD,TRO1)=PHI1/(TRO1-CSQD*(PHI1**2))
      TJM3F(PHI1,CSQD,TRO1)=(PHI1*TRO1)/(TRO1-CSQD*(PHI1**2))
C*****THE ERROR FUNCTION VELOCITY PROFILE, PHI(I), IS INITIALIZED IN
C     *BLOCK DATA* AND STORED IN LABELED COMMON *ERFVP*. PHI(I) IS
C     GIVEN FOR I=1,350 VALUES OF ETA IN THE RANGE OF ETA=-3.5 TO
C     ETA=3.5 IN INCREMENTS OF DETA=0.02
C*****INCREMENT SIZE AND INITIAL VALUES AT (ETA RB) ARE SPECIFIED HERE.
      DETA=0.02
      TRO(1)=TRBO
      EI1(1)=0.0
      EI3(1)=0.0
C*****CALCULATION OF THE MIXING TABLE BY THE TRAPEZOIDAL RULE.
      DO 2,I=1,349
      TRO(I+1)= (TRBO + (1.0-TRBO)*PHI(I+1))
      EI1(I+1)= EI1(I) + 0.5*(TJM1F(PHI(I+1),CSQD,TRO(I+1)) +
     1          TJM1F(PHI(I),CSQD,TRO(I)))*DETA
      EI3(I+1) = EI3(I) + 0.5*(TJM3F(PHI(I+1),CSQD,TRO(I+1)) +
     1          TJM3F(PHI(I),CSQD,TRO(I)))*DETA
      IF (PHI(I+1).GE.PHID) GO TO 3
    2 CONTINUE
C*****DETERMINE THE D-STREAMLINE VALUES OF THE INTEGRALS
C
    3 EI1D=EI1(I)+((EI1(I+1)-EI1(I))/(PHI(I+1)-PHI(I)))*
     1     (PHID-PHI(I))
      EI3D=EI3(I)+((EI3(I+1)-EI3(I))/(PHI(I+1)-PHI(I)))*
     1     (PHID-PHI(I))
      RETURN
      END
      FUNCTION SIGMAF (CSQD,TRBO,GAMMA,NSIGMA)
C*****THIS FUNCTION CALCULATES THE VALUE OF THE SIMILARITY PARAMETER,
C     SIGMA, FROM THE CORRELATIONS OF KORST AND TRIPP OR CHANNAPRAGADA
C
C     NSIGMA= 0,SIGMA AFTER KORST AND TRIPP
C     NSIGMA= 1,SIGMA AFTER CHANNAPRAGADA
C
```

```
      IF (NSIGMA.NE.0) GOTO 1
C*****  KURST AND TRIPP  **************************************************
      SIGMAF= 12.0+2.758*2.0*CSOD/((1.0-CSOD)*(GAMMA-1.0))
      RETURN
C
C*****  CHANNAPRAGADA  ****************************************************
    1 IF (CSOD-0.7) 2,3,3
    2 R=0.25
      GOTO 4
    3 R=0.5*(CSOD-0.7)+0.25
    4 SIGMAF = 12.0/(R*(1.0+(1.0-CSOD)/TRHO))
      RETURN
      END
      BLOCK DATA
C*****THE ERROR FUNCTION VELOCITY PROFILE, PHI(I), IS INITIALIZED IN
C     *BLOCK DATA* AND STORED IN LABELED COMMON *ERFVP*.  PHI(I) IS
C     GIVEN FOR I=1,350 VALUES OF ETA IN THE RANGE OF ETA=-3.5 TO
C     ETA=3.5 IN INCREMENTS OF DETA=0.02.
C
      COMMON  /ERFVP/ A1(45),A2(45),A3(45),A4(45),A5(45),A6(45),A7(45),
     1   A8(35)
      DATA  A1
     * /0.000000 ,  0.000000 ,  0.000000 ,  0.000000 ,  0.000000 ,
     *  0.000000 ,  0.000001 ,  0.000001 ,  0.000001 ,  0.000001 ,
     *  0.000001 ,  0.000001 ,  0.000002 ,  0.000002 ,  0.000002 ,
     *  0.000003 ,  0.000003 ,  0.000004 ,  0.000004 ,  0.000005 ,
     *  0.000005 ,  0.000006 ,  0.000007 ,  0.000008 ,  0.000009 ,
     *  0.000011 ,  0.000012 ,  0.000014 ,  0.000016 ,  0.000018 ,
     *  0.000020 ,  0.000023 ,  0.000026 ,  0.000029 ,  0.000033 ,
     *  0.000037 ,  0.000042 ,  0.000047 ,  0.000053 ,  0.000059 ,
     *  0.000067 ,  0.000075 ,  0.000084 ,  0.000094 ,  0.000105 /
      DATA  A2
     * /0.000118 ,  0.000131 ,  0.000147 ,  0.000164 ,  0.000182 ,
     *  0.000203 ,  0.000226 ,  0.000251 ,  0.000279 ,  0.000310 ,
     *  0.000344 ,  0.000381 ,  0.000422 ,  0.000467 ,  0.000517 ,
     *  0.000571 ,  0.000631 ,  0.000696 ,  0.000767 ,  0.000845 ,
     *  0.000931 ,  0.001024 ,  0.001126 ,  0.001237 ,  0.001358 ,
     *  0.001489 ,  0.001632 ,  0.001788 ,  0.001956 ,  0.002140 ,
     *  0.002338 ,  0.002553 ,  0.002786 ,  0.003038 ,  0.003310 ,
     *  0.003604 ,  0.003921 ,  0.004263 ,  0.004631 ,  0.005027 ,
     *  0.005454 ,  0.005912 ,  0.006404 ,  0.006932 ,  0.007498 /
      DATA  A3
     * /0.008104 ,  0.008753 ,  0.009446 ,  0.010188 ,. 0.010980 ,
     *  0.011825 ,  0.012725 ,  0.013685 ,  0.014706 ,  0.015792 ,
     *  0.016946 ,  0.018172 ,  0.019472 ,  0.020851 ,  0.022311 ,
     *  0.023857 ,  0.025491 ,  0.027219 ,  0.029043 ,  0.030967 ,
     *  0.032996 ,  0.035133 ,  0.037382 ,  0.039747 ,  0.042233 ,
     *  0.044843 ,  0.047582 ,  0.050453 ,  0.053460 ,  0.056607 ,
     *  0.059899 ,  0.063338 ,  0.066930 ,  0.070677 ,  0.074583 ,
     *  0.078652 ,  0.082887 ,  0.087291 ,  0.091868 ,  0.096620 ,
     *  0.101550 ,  0.106661 ,  0.111955 ,  0.117434 ,  0.123101 /
      DATA  A4
     * /0.128956 ,  0.135002 ,  0.141239 ,  0.147669 ,  0.154292 ,
     *  0.161108 ,  0.168110 ,  0.175322 ,  0.182716 ,  0.190305 ,
     *  0.198084 ,  0.206051 ,  0.214705 ,  0.222544 ,  0.231065 ,
     *  0.239765 ,  0.248641 ,  0.257688 ,  0.266904 ,  0.276283 ,
     *  0.285822 ,  0.295514 ,  0.305354 ,  0.315338 ,  0.325457 ,
     *  0.335708 ,  0.346082 ,  0.356572 ,  0.367173 ,  0.377876 ,
     *  0.388673 ,  0.399557 ,  0.410519 ,  0.421552 ,  0.432647 ,
     *  0.443795 ,  0.454988 ,  0.466217 ,  0.477472 ,  0.498746 ,
     *  0.500029 ,  0.511311 ,  0.522585 ,  0.533840 ,  0.545069 /
      DATA  A5
     * /0.556261 ,  0.567409 ,  0.578504 ,  0.589536 ,  0.600496 ,
```

```
*  0.611382 ,  0.622179 ,  0.632881 ,  0.643480 ,  0.653971 ,
*  0.664334 ,  0.674593 ,  0.684717 ,  0.694695 ,  0.704534 ,
*  0.714226 ,  0.723763 ,  0.733141 ,  0.742356 ,  0.751403 ,
*  0.760278 ,  0.768977 ,  0.777497 ,  0.785434 ,  0.793988 ,
*  0.801954 ,  0.809731 ,  0.817317 ,  0.824712 ,  0.831915 ,
*  0.838923 ,  0.845739 ,  0.852361 ,  0.858789 ,  0.865026 ,
*  0.871070 ,  0.876925 ,  0.882590 ,  0.888068 ,  0.893361 ,
*  0.898471 ,  0.903400 ,  0.908151 ,  0.912726 ,  0.917130 /
 DATA  A6
* /0.921364 ,  0.925432 ,  0.929337 ,  0.933083 ,  0.936674 ,
*  0.940113 ,  0.943404 ,  0.946550 ,  0.949557 ,  0.952427 ,
*  0.955165 ,  0.957774 ,  0.960259 ,  0.962674 ,  0.964873 ,
*  0.967009 ,  0.969037 ,  0.970961 ,  0.972785 ,  0.974511 ,
*  0.976146 ,  0.977691 ,  0.979151 ,  0.980529 ,  0.981829 ,
*  0.983054 ,  0.984208 ,  0.985293 ,  0.986314 ,  0.987274 ,
*  0.988174 ,  0.989018 ,  0.989810 ,  0.990551 ,  0.991245 ,
*  0.991894 ,  0.992500 ,  0.993065 ,  0.993593 ,  0.994085 ,
*  0.994543 ,  0.994969 ,  0.995365 ,  0.995733 ,  0.996075 /
 DATA  A7
* /0.996392 ,  0.996686 ,  0.996958 ,  0.997210 ,  0.997442 ,
*  0.997657 ,  0.997856 ,  0.998039 ,  0.998208 ,  0.998363 ,
*  0.998506 ,  0.998638 ,  0.998758 ,  0.998869 ,  0.998971 ,
*  0.999064 ,  0.999149 ,  0.999227 ,  0.999299 ,  0.999364 ,
*  0.999424 ,  0.999478 ,  0.999527 ,  0.999572 ,  0.999613 ,
*  0.999651 ,  0.999685 ,  0.999715 ,  0.999743 ,  0.999768 ,
*  0.999791 ,  0.999812 ,  0.999831 ,  0.999848 ,  0.999863 ,
*  0.999877 ,  0.999889 ,  0.999900 ,  0.999910 ,  0.999919 ,
*  0.999927 ,  0.999935 ,  0.999941 ,  0.999947 ,  0.999952 /
 DATA  A8
* /0.999957 ,  0.999961 ,  0.999965 ,  0.999968 ,  0.999971 ,
*  0.999974 ,  0.999976 ,  0.999978 ,  0.999980 ,  0.999982 ,
*  0.999983 ,  0.999984 ,  0.999985 ,  0.999986 ,  0.999987 ,
*  0.999988 ,  0.999989 ,  0.999989 ,  0.999990 ,  0.999990 ,
*  0.999991 ,  0.999991 ,  0.999991 ,  0.999992 ,  0.999992 ,
*  0.999992 ,  0.999992 ,  0.999992 ,  0.999992 ,  0.999993 ,
*  0.999993 ,  0.999993 ,  0.999993 ,  0.999993 ,  0.999993 /
 END
$PEND
```

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